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Effectiveness of technological interventions to improve healthcare communication with children with long-term conditions: a systematic review and meta-analysis of randomised controlled trials

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Abstract:	Objective: This systematic review and meta-analysis aimed to evaluate the effectiveness of technological interventions used to improve communication between healthcare professionals (HCPs) and children with long-term conditions (LTCs). Methods: PROSPERO: CRD42020221977 . Five electronic databases were searched from inception to May 2021 for randomised controlled trials. Study characteristics were described and random-effects meta-analysis was conducted. Results: Nineteen studies were included, involving 1995 participants. Technological interventions were found to significantly improve participants' knowledge of their condition (standardised mean difference [SMD] 0.39; 95% CI 0.07-0.71; p = 0.02) and lead to a more internal health locus of control (SMD 0.50; 95% CI 0.25-0.76; p < 0.0001). There was no statistically significant improvement in physiological measures or emergency healthcare use. Conclusion: This systematic review showed some benefits of using technology to improve communication between HCPs and children with LTCs. Future primary research should use rigorous methods for subsequent reviews to draw conclusions with greater confidence in the evidence. Establishing a core outcome set within this field of study would enable consistent measurement of outcomes. Practice implications: Our findings indicate value in integrating communication technologies in the child health setting, aiming to establish greater continuity of care and maintain patient-clinician relationships between healthcare visits.

Title: Effectiveness of technological interventions to improve healthcare communication with children with long-term conditions: a systematic review and meta-analysis of randomised controlled trials

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Abstract

Objective:

This systematic review and meta-analysis aimed to evaluate the effectiveness of technological interventions used to improve communication between healthcare professionals (HCPs) and children with long-term conditions (LTCs).

Methods:

PROSPERO: CRD42020221977. Five electronic databases were searched from inception to May 2021 for randomised controlled trials. Study characteristics were described and random-effects meta-analysis was conducted.

Results:

Nineteen studies were included, involving 1995 participants. Technological interventions were found to significantly improve participants' knowledge of their condition (standardised mean difference [SMD] 0.39; 95% CI 0.07-0.71; $p = 0.02$) and lead to a more internal health locus of control (SMD 0.50; 95% CI 0.25-0.76; $p < 0.0001$). There was no statistically significant improvement in physiological measures or emergency healthcare use.

Conclusion:

This systematic review showed some benefits of using technology to improve communication between HCPs and children with LTCs. Future primary research should use rigorous methods for subsequent reviews to draw conclusions with greater confidence in the evidence. Establishing a core outcome set within this field of study would enable consistent measurement of outcomes.

Practice implications:

Our findings indicate value in integrating communication technologies in the child health setting, aiming to establish greater continuity of care and maintain patient-clinician relationships between healthcare visits.

1. Introduction

1.1 Background

In the United Kingdom, 16% of children aged five to 15 years are reported to have at least one long-term health condition, but the effectiveness of technology to support adaptation and self-management of their condition is currently not known [1]. Living with a long-term condition (LTC) can significantly affect the quality-of-life of a child and their family [2]. Frequent encounters with healthcare services may impact upon school attendance and participation in hobbies, which could affect a child's development and psychosocial wellbeing [3,4]. While children and their families may experience uncertainty when faced with a diagnosis of a LTC, effective communication between healthcare professionals (HCPs) and the child is of great importance to encourage the child's contribution to the management of their condition. The World Health Organization values the importance of effective communication and meaningful participation of children in their care, highlighting their influence on a child's "involvement in decision-making, development, learning and progressive autonomy" [5].

Research demonstrates that children want to be involved in their healthcare, and while the information conveyed needs to be adapted to suit the age and intellectual ability of the child, effective communication can improve physiological and psychosocial outcomes [6-8]. By establishing effective patient-HCP communication, children are able to build fundamental

skills such as problem-solving, decision-making and resource utilisation, building 'health literacy' at a crucial time in their lives [9]. Health literate children can become more proactive and responsible for their own wellbeing and adopt health-promoting behaviours that they can take into adulthood [10].

Within the scope of communication, the use of technological devices such as mobile phones, tablets and computers has risen substantially in the healthcare setting over recent years. There have been over 300,000 health-related apps developed and an even greater shift in how patients interact with the healthcare system has been observed during the COVID-19 pandemic with 'virtual consultations' increasingly common [11,12]. However, these interventions are often aimed at adults and have not yet been universally accepted in the child health setting. As younger children become increasingly technology-literate, there is an emerging audience that has the potential to make use of these methods of audiovisual communication to learn about their LTC in an accessible and engaging way [5].

Previous literature reviews in the child health setting have focused mainly on the use of technology for specific conditions or modalities of communication [13-20]. Many place particular emphasis on improving adolescents' self-management during the transition to adult healthcare services, with varying levels of success [13,17,18]. Some reviews date back over five years during which time personal devices have become more affordable and accessible. UK smartphone ownership in five to 15 year olds has increased from 35% in 2015 to 45% in 2019, and one-quarter of three and four year olds now have access to a tablet [21]. Hence, it is timely to review the effectiveness and future of communication technologies in child health, without restriction on age or type of LTC.

1.2 Aim and objectives

This systematic review aimed to evaluate the effectiveness of technological interventions used to improve communication between HCPs and children of all ages with LTCs.

The objectives were to:

- Characterise the types of technological interventions, types of LTCs and age ranges of the children studied in the literature.
- Evaluate the effectiveness of the technological interventions described through synthesis and meta-analysis of cognitive, affective, physiological and health outcomes.

2. Methods

2.1 Protocol and registration

This review was registered with the International Prospective Register of Systematic Reviews (PROSPERO): CRD42020221977 [22]. The methods follow guidance from the Cochrane Handbook for Systematic Reviews of Interventions and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Supplementary File 1) [23,24].

2.2 Information sources

Five electronic databases (MEDLINE, Embase, Emcare, PsycINFO and Scopus) were searched from inception to May 2021. Further articles were identified through backward and forward citation searching of selected studies and any systematic reviews retrieved in the search. Journals most frequently associated with selected studies were hand-searched.

2.3 Search strategy

The search strategy for this review was developed using medical subject headings and free-text terms using the Boolean operator 'AND'. A search string was created for randomised controlled trials (RCTs) studying children aged 18 years and younger, including search layers for LTCs, HCPs, communication and interventions using the assistance of technology (Supplementary File 2). There was no restriction placed on publication date. The search included British and North American spellings and non-English language studies to account for French and Dutch languages which were included for review.

2.4 Study selection

Assessment of study inclusion was carried out by two reviewers (ED and AA). Each article was screened using the eligibility criteria (Box 1, Supplementary File 2) by title and abstract. Articles that met the criteria were then screened in full-text. ED and AA independently screened 10% of the studies yielded from the database search. Inter-rater reliability was calculated to be 0.85 using Cohen's kappa coefficient, indicating "almost perfect" agreement [25]. Following this, ED completed screening of the remaining articles. Any uncertainty about inclusion of a study was resolved by discussion with KJL and AE.

INSERT BOX 1 HERE

2.5 Data extraction

Data extraction was completed by one reviewer (ED) and a second reviewer (AA) independently examined all extracted data for consistency. Trial identification number was recorded to prevent duplicate studies being missed. EndNote reference manager was used to handle included studies and data pertaining to sample characteristics, study design,

intervention details and outcome measures of effectiveness were extracted [26]. Means, standard deviations, p-values and sample sizes were extracted from the intervention and control groups of included studies. Microsoft Excel was used to collate statistical data for meta-analysis [27].

2.6 Risk of bias assessment

The Cochrane Collaboration Risk of Bias 2 (RoB 2) tool was used by one reviewer (ED) to determine risk of bias arising from each study [28]. The inferences made from the RoB 2 assessment were used during meta-analysis sensitivity analyses. Reporting biases were presented using funnel plots.

2.7 Outcomes

We sought outcomes across cognitive, affective, physiological and health domains [22]. The outcomes reported in the included studies were allocated to one of these four domains based on the measurement tool components and how they correspond to children's progression to improved LTC management.

2.8 Data synthesis and analysis

Narrative synthesis:

Narrative synthesis was performed to summarise study characteristics, interventions and heterogeneous results between studies using a structured approach [29].

Meta-analysis:

Meta-analysis was conducted by one reviewer (ED) using the Cochrane Collaboration's Review Manager (version 5.4) [30]. A second reviewer (AA) checked all data entered. The

study outcomes for meta-analysis were knowledge, health locus of control, physiological measures and emergency healthcare use. These outcomes were those most frequently measured in the included studies, where there was sufficient homogeneity and data for inclusion [22]. Studies that measured outcomes of interest and provided sufficient baseline and follow-up data were included.

Standardised mean difference (SMD) between baseline and endpoint was generated using a random-effects model at a 95% confidence interval (CI). 'Random-effects' was chosen due to the range of measurement tools used in the studies. Statistical significance was assumed at a p-value <0.05. Heterogeneity was reported using the I^2 statistic. Mean and standard deviation differences were calculated, according to guidance from chapter 6.5 of the Cochrane Handbook for Systematic Reviews of Interventions (Supplementary File 3) [23]. The correlation coefficient was calculated for each of the four outcomes. The coefficients were derived using data from studies that reported sufficient detail, and from this, an average was calculated.

Subgroup analyses were based on the following study characteristics: ages of the study participants, LTCs targeted by the intervention and types of technologies used in the intervention [22]. Sensitivity analyses were undertaken to establish robustness of the meta-analysis results. Studies indicating a high risk of bias were removed as part of the *a priori* sensitivity analysis. Additionally, only studies exhibiting a low risk of bias were included *post hoc* due to some outcomes having no studies that demonstrated high risk of bias. The Grading of Recommendations, Assessment, Development and Evaluations (GRADE) approach was used to comment on the quality of evidence for each outcome studied during meta-analysis [31].

3. Results

3.1 Study selection

During the study selection process, database searches yielded 2669 results and an additional 15 papers were identified through other sources. Following removal of duplicates, 1371 records were assessed for eligibility. Full-text screening was undertaken on 70 papers and 19 papers were included for review (Figure 1). Excluded reports that were assessed by full-text are detailed in Supplementary File 4.

INSERT FIGURE 1 HERE

3.2 Study characteristics

The 19 included studies enrolled a total of 1995 participants [32-50]. Of the papers that reported sufficient demographic data, the mean age was 12.4 years (range 3-18 years) and 55.6% of participants were male. Fifteen RCTs were conducted in the United States, with other studies based in the United Kingdom *(n = 2)*, Taiwan *(n = 1)* and Turkey *(n = 1)*. The average follow-up period was 5.3 months (range 3 weeks-12 months).

The following conditions were examined: asthma *(n = 11)*, type 1 diabetes *(n = 4)*, cancer *(n = 2)*, epilepsy *(n = 1)* and encopresis *(soiling; n = 1)*. Further study characteristics, details of the intervention and control groups and results summary are presented in Table 1.

INSERT TABLE 1 HERE

Common aims of the interventions were to improve the child's knowledge of their LTC, their self-management behaviours and communication with HCPs. These HCPs were a range of

consultant physicians *(n = 14)*, nurses *(n = 7)* and general practitioners *(n = 2; total n exceeds number of papers due to some studies taking a multidisciplinary approach to healthcare communication).*

For the calculation of standard deviation differences during meta-analysis, the correlation coefficient ranged from 0.47 to 0.59.

3.3 Risk of bias assessment

Each study's methodology was appraised as low risk, some concerns about risk or high risk of bias (Supplementary File 5). Four studies were assessed as carrying a low risk of bias [42,44,46,47]. Those at higher risk of bias were commonly due to deviations in the delivery of the intervention, participant attrition and variable blinding of participants and researchers (Figure 2).

INSERT FIGURE 2 HERE

3.4 Intervention types

Interventions identified in this review were divided into four groups: interactive websites *(n = 7)*, character-based video games *(n = 6)*, text-messaging *(n = 3)* and other *(n = 3)*. Most interventions were accessed by participants in their own home, however two were delivered at outpatient clinics [37,44], one was accessed at the participants' schools [42] and one at a community health centre [47].

Intervention exposure time, including duration and frequency of sessions, varied greatly between studies. Ten groups were given per-protocol access to the technologies, standard

across all participants [35-39,42,44,45,47,50], whereas nine were given unrestricted access for the duration of the study [32-34,40,41,43,46,48,49]. **Intervention uptake was inconsistently reported; studies where this was included recorded uptake ranging from 50% to 93%, with video games exhibiting the highest interaction rates (mean = 84%).**

The fundamental aim of all included interventions was to share information for discussion between HCPs and children, with many studies citing the objectives of patient education and knowledge acquisition. Notably, only seven studies adopted theoretical models of behaviour change during intervention design and development [33,34,36,38,42,49,50]. Amongst these were the Health Belief Model and motivational interviewing, both of which have demonstrated benefits in patient communication and overcoming personal barriers to motivation and self-efficacy [51,52].

The communication approaches implemented during these interventions were wide-ranging and may be categorised as either adopting a 'giving' or 'receiving' information strategy, with many technologies employing both methods. Examples of 'information giving' included conveying knowledge through the simple provision self-management components [34,35,37,41,46] or through alert-based communication such as medication dosing reminders [40]. 'Information receiving' took different forms such as challenging children's perceptions of their LTC [36], requesting medication compliance information [39] and giving children the opportunity to answer HCPs' questions [50], creating a more reflective and actionable communication environment.

Interactive websites:

Seven studies included in this review delivered interventions using websites [32,39,42,43,46,48,49]. Participants worked through interactive, educational modules which included illustrations, animated tutorials, reinforcing quizzes and electronic diaries to exchange information about their condition and self-management. The websites were accessible by computer, tablet or mobile phone and were mostly made available to participants for the study's duration.

Character-based video games:

Six studies used animated, character-based video games to interact with children about their LTC [33,34,37,38,45,47]. Five interventions were delivered using computers, and one study provided participants with a *Nintendo* console for six months [33]. The interventions involved a protagonist who engaged participants through competition and challenge motivators. Participants were usually able to select a relatable gender and ethnicity for their character. Plots included a secret agent-themed asthma mission [45], *Packy* and *Marlon* elephant friends at a diabetes summer camp [33] and *Space Buddy* who explores leukaemia planet, *Leukator* [34]. Of the studies that provided participant mean ages, this subgroup had a lower mean age of 8.6 years, compared to 12.4 years for all studies included in this review.

Text-messaging:

Three studies used two-way text-messaging to improve healthcare communication [36,40,50]. Scheduled questions were sent to participants' mobile phones every 1-2 days, and they were able to reply with single letters or short texts. Two studies focused on knowledge and symptom awareness questions [36,50] and the other enquired about asthma medication use to improve adherence [40]. All three studies required the participants to have their own mobile

phone (in line with the review's criteria of the children interacting with the technology) which was reflected in the older age of this subgroup (mean = 13.9 years).

Other interventions:

The remaining studies used a range of techniques to deliver interventions. Two studies used a CD-ROM to provide multimedia educational content without the use of Internet or a character plot [41,44]. A third study used a device that connected to the participants' home telephones and the child was able to answer asthma symptom and trivia questions by pressing the keypad [35].

3.5 Control groups

Control groups received active *(n = 11)* or inactive *(n = 8)* variants of care (Table 1). Inactive controls received either standard care or non-educational video games that were unrelated to healthcare. Active controls were provided with a range of alternative self-management education resources (such as written materials and face-to-face appointments with HCPs) and these participants received similar exposure times as their intervention counterparts.

3.6 Effectiveness of technological interventions

The findings reported by the included studies were generally positive, with improvements observed in a range of domains. While there was variation in levels of significance for the outcomes measured, none of the studies demonstrated detrimental effects from the interventions.

3.6.1 Cognitive outcomes

Knowledge:

Fourteen studies reported participant knowledge as an outcome and 11 of these were included for meta-analysis (Figure 3). Knowledge of their condition was measured in a variety of ways using validated tests or questions composed by the study researchers. This methodological diversity culminated in substantial heterogeneity (I^2 = 70%) [23]. The combined data demonstrated a statistically significant improvement in the intervention groups' knowledge compared with the control groups (SMD 0.39; 95% CI 0.07,0.71; p = 0.02). However, only the video game interventions sustained this level of significance during subgroup analysis (SMD 0.44; 95% CI 0.05,0.83; p = 0.03), whereas the website, text-messaging and CD-ROM interventions did not. There was no significant difference between knowledge outcomes for particular age groups (p = 0.87) or for studies delivering interventions for asthma versus diabetes (p = 0.35). GRADE strength of evidence for this outcome was judged to be 'low' (Supplementary File 6) and all forest plots can be accessed in Supplementary File 7.

INSERT FIGURE 3 HERE

3.6.2 Affective outcomes

Health locus of control:

Health locus of control (i.e. the belief that health is in one's control) was measured by four studies using validated tools such as the Children's Health Locus of Control [53]. In the literature, a positive development of control is described as a 'more internal' locus of control [54]. Intervention groups displayed a more internal health locus of control compared with the control groups, at a statistically significant level (SMD 0.50; 95% CI 0.25,0.76; p < 0.001; I^2 = 0%) (Figure 4). Subgroup analyses were not performed owing to the small sample size for

this outcome. Using the GRADE approach, this outcome had 'moderate' strength of evidence.

INSERT FIGURE 4 HERE

3.6.3 Physiological outcomes

Physiological measures:

Physiological data from diabetes and asthma studies were reported by eight papers, using glycated haemoglobin (HbA_{1c}) and lung function tests respectively. Meta-analysis was performed on six of these studies. No significant differences for the measures were found for the diabetes studies (n = 3; SMD 0.16; 95% CI -0.19,0.51; p = 0.38) or the asthma studies (n = 3; SMD 0.08; 95% -0.18,0.35; p = 0.54). This outcome demonstrated 'very low' strength of evidence based on GRADE criteria.

3.6.4 Health outcomes

Self-management:

Four studies reported improvements in participants' self-efficacy [33,40,41,48], however only two were found to be significantly increased compared with control groups [40,48]. Another method of measuring self-management was through children's medication compliance, reported in four studies [35,39,40,49]. Compared with controls, this was significantly improved in two studies [39,40].

Symptoms:

Findings relating to asthma symptoms was reported in seven studies [35,37-39,42,44,49]. Presence of respiratory symptoms such as coughing and wheezing were shown to be reduced

in five studies [35,39,42,44,49], with three of these demonstrating significantly improved daytime symptoms compared with control groups [39,42,44]. Two studies investigated changes in severity of these symptoms [37,38], with only one reporting milder symptoms [37]. No papers studying the other LTCs under review reported symptom outcomes.

Emergency healthcare use:

Eight papers studied emergency healthcare use, an outcome measured by urgent physician visits, emergency department visits or hospitalisations. Through meta-analysis of four studies, there was a trend in favour of interventions reducing urgent physician and emergency department visits, but this was not statistically significant (SMD -0.20; 95% CI -0.42,0.02; p = 0.08; I^2 = 0%). Subgroup analysis of urgent physician versus emergency department encounters demonstrated the same pattern of results. While there were insufficient data to perform meta-analysis on hospitalisation rates, interventions followed a similar pattern of non-significant improvement. There was 'moderate' strength of evidence using the GRADE approach.

Quality-of-life:

Quality-of-life was measured in six studies using tools such as the Diabetes Quality-of-Life for Youth and Paediatric Asthma Quality-of-Life Questionnaires [36,38-41,50]. Four studies noted improvements in quality-of-life following use of interventions [36,39,40,50], with one study having statistically significant improvements compared with the control group [40]. Han et al. demonstrated significant improvements in only the 'impact' and 'worries' quality-of-life domains [36].

3.6.5 Sensitivity analyses

Sensitivity analyses were undertaken by excluding studies that exhibited high risk of bias [32,36,45] and including only studies with low risk of bias [42,44,46,47], according to the Cochrane RoB 2 tool. Two studies were removed from the meta-analysis of 11 studies for condition knowledge and this resulted in an outcome that no longer displayed statistical significance ($p = 0.09$) (Supplementary File 7) [32,45]. However, when analysing data grouped only from studies with low risk of bias, the effect size and significance were improved (SMD 0.68, favouring intervention; 95% CI 0.17,1.18; $p = 0.009$). Studies removed from the health locus of control and physiological measures outcomes did not change the judgements reached. No studies included in the emergency healthcare use outcome demonstrated high risk of bias. There were no changes when retaining only the low risk of bias studies for emergency healthcare use. There were insufficient studies to determine whether reporting biases were present (Supplementary File 8).

4. Discussion and conclusion

4.1 Discussion

The studies in this systematic review reported a variety of outcomes relating to children's management of their LTC. The majority of studies demonstrated positive findings for outcomes such as self-management behaviours, presence of symptoms and quality-of-life, though many of these were not significantly improved compared with controls. Meta-analyses found that technological interventions improve children's LTC knowledge and cultivate a more internal health locus of control, but do not significantly affect clinical outcomes: physiological measures and emergency healthcare use. Subgroup analysis suggested **higher uptake rates and** favourable knowledge outcomes for video game interventions compared to other technologies studied. **This may direct design**

considerations of future child health communication interventions. The studies evaluating the effectiveness of character-based video games considered the appeal of this communication modality, emphasising children's attraction to fun graphics, instantaneous feedback and the "enveloping personal experience" of virtual reality [33,47].

This review used established guidance and validated tools, thus was methodologically rigorous [23,24,28]. Using inclusive eligibility criteria for all LTCs and technological interventions supports generalisability within the field of child health, compared to other published works [13-20]. Meta-analysis of adequately reported outcomes was undertaken, overcoming issues such as small sample sizes within individual studies. However, there are some limitations at individual level that warrant caution with the presented findings. Methodological standards varied greatly and there were concerns about risk of bias for most included studies, consistent with other reviews in this field [15,55]. Measures were taken to reduce the impact of this within the review, such as including only RCTs and conducting sensitivity analyses. Nevertheless, when applying the GRADE framework, the meta-analysis results demonstrated 'very low' to 'moderate' strengths of evidence and the findings should therefore be interpreted with caution.

This review did not examine measures relating to communication specifically, rather the outcomes of effective communication with HCPs on condition self-management. There was heterogeneity of participant demographics, interventions and outcome measures under review. This was partially overcome through the use of random effects meta-analysis and *a priori* subgroup analyses, however it is difficult to determine the influence of additional, potentially important variables such as intervention contact time and follow-up time on effect

size [22]. Given the lack of homogeneous data, the identified outcomes and subgroups were limited and prevented meta-analysis for other outcomes of interest such as symptom severity and quality-of-life. However, there is evolving interest in patient-centred technologies and future studies are likely to contribute to the evidence base, allowing for larger-scale meta-analyses and more detailed evaluation of these interventions.

To date, reviews completed in this area have focused on specific conditions [16,19], interventions [14,15,18,19] or outcomes [13,16], often aimed at adolescents transitioning to adult healthcare services [13,17,18, 20]. This review provides a broader appraisal of the current evidence, encompassing all technological communication interventions aimed at children without restriction on type of LTC. Similar to our findings, previous reviews reported results that were cautiously favourable towards technological interventions, but with a shortage of high-quality studies.

To direct future clinical practice, further research into technological interventions is required. Establishing a core outcome set within this field would enable consistent measurement of outcomes during primary research [56]. With the addition of high-quality studies that conform to these core outcomes, future systematic reviews will be able to complete more precise meta-analyses. This could include further subgroup analyses, such as impacts of different intervention modalities, **use of conceptual models during design stages,** contact and follow-up times, **and caregiver involvement on effectiveness. This review provides a novel perspective on interventions targeted directly at children, however given the role caregivers play in facilitating and influencing the use of the technologies, determining their contribution to intervention effectiveness is important to evaluate as well.**

4.2 Conclusion

This systematic review showed some benefits of using technology to improve communication between healthcare professionals and children with a range of long-term health conditions. To our knowledge, this study is the first to examine specific health-related outcomes for a range of technologies through meta-analysis. It is vital that future primary research adheres to rigorous and consistent methods to enable subsequent reviews to draw conclusions with greater confidence in the evidence. Ultimately, these technologies hope to provide a more seamless and accessible multidisciplinary healthcare experience for children and their families, empowering and facilitating the self-management of their long-term conditions.

4.3 Practice implications

Our findings support the integration of communication technologies in the child health setting. The interventions identified aim to establish greater continuity of care and maintain patient-clinician relationships between healthcare visits. **This review supports the development of future child health communication interventions and demonstrates particular benefits of video games in improving children's knowledge.**

The acceptance of these technologies by healthcare professionals, children and their caregivers should be assessed and supported to ensure the successful implementation of these interventions into clinical practice. This includes research that provides a greater insight into the barriers and strategies for real-world implementation of communication technologies to guide actionable practice and policy recommendations.

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Declaration of competing interest

Declarations of interest: none.

References

1. National Health Service. Health Survey for England 2018: Children's Health, https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/2018; 2019 [accessed 17 May 2021].

2. Sartain SA, Clarke CL, R Heyman. Hearing the voices of children with chronic illness. J Adv Nurs. 2000;32:913-21.

3. Van Cleave J, Gortmaker SL, Perrin JM. Dynamics of obesity and chronic health conditions among children and youth. JAMA. 2010;303:623-30. https://doi.org/10.1001/jama.2010.104.

4. Barlow JH, Ellard DR. The psychosocial well-being of children with chronic disease, their parents and siblings: an overview of the research evidence base. Child Care Health Dev. 2006;32:19-31. https://doi.org/10.1111/j.1365-2214.2006.00591.x.

5. World Health Organization. Standards for improving the quality of care for children and young adolescents in health facilities. Geneva: World Health Organization; 2018.

6. Jordan A, Wood F, Edwards A, Shepherd V, Joseph-Williams N. What adolescents living with long-term conditions say about being involved in decision-making about their healthcare: a systematic review and narrative synthesis of preferences and experiences. Patient Educ Couns. 2018;101:1725-35. https://doi.org/10.1016/j.pec.2018.06.006.

7. Stewart MA. Effective physician-patient communication and health outcomes: a review. CMAJ. 1995;152:1423-33.

8. Diette GB, Skinner EA, Markson LE, Algatt-Bergstrom P, Nguyen TT, Clark RD et al. Consistency of care with national guidelines for children with asthma in managed care. J Pediatr. 2001;138:59-64. https://doi.org/10.1067/mpd.2001.109600.

9. Lorig KR, Holman HR. Self-management education: history, definition, outcomes, and mechanisms. Ann Behav Med. 2003;26:1-7. https://doi.org/10.1207/S15324796ABM2601_01.

10. Sawyer SM, Afifi RA, Bearinger LH, Blakemore SJ, Dick B, Ezeh AC et al. Adolescence: a foundation for future health. Lancet. 2012;379:1630-40. https://doi.org/10.1016/S0140-6736(12)60072-5.

11. Gordon WJ, Landman A, Zhang H, Bates DW. Beyond validation: getting health apps into clinical practice. NPJ Digit Med. 2020;3:14. https://doi.org/10.1038/s41746-019-0212-z.

12. Keesara S, Jonas A, Schulman K. Covid-19 and health care's digital revolution. N Engl J Med. 2020;382:e82. https://doi.org/10.1056/NEJMp2005835.

13. Bass AM, Farhangian ME, Feldman SR. Internet-based adherence interventions for treatment of chronic disorders in adolescents. Adolesc Health Med Ther. 2015;6:91-9. https://doi.org/10.2147/AHMT.S56065.

14. Charlier N, Zupanic N, Fieuws S, Denhaerynck K, Zaman B, Moons P. 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. 2016;23:230-9. https://doi.org/10.1093/jamia/ocv100.

15. Fedele DA, Cushing CC, Fritz A, Amaro CM, Ortega A. Mobile health interventions for improving health outcomes in youth: a meta-analysis. JAMA Pediatr. 2017;171:461-9. https://doi.org/10.1001/jamapediatrics.2017.0042.

16. Lim NLY, Shorey S. Effectiveness of technology-based educational interventions on the empowerment related outcomes of children and young adults with cancer: a quantitative systematic review. J Adv Nurs. 2019;75:2072-84. https://doi.org/10.1111/jan.13974.

17. Low JK, Manias E. Use of technology-based tools to support adolescents and young adults with chronic disease: systematic review and meta-analysis. JMIR Mhealth Uhealth. 2019;7:e12042. https://doi.org/10.2196/12042.

18. Majeed-Ariss R, Baildam E, Campbell M, Chieng A, Fallon D, Hall A et al. Apps and adolescents: a systematic review of adolescents' use of mobile phone and tablet apps that support personal management of their chronic or long-term physical condition. J Med Internet Res. 2015;17:e287. https://doi.org/10.2196/jmir.5043.

19. Rewolinski JA, Kelemen A, Liang Y. Type I diabetes self-management with game-based interventions for pediatric and adolescent patients. Comput Inform Nurs. 2020;39:78-88. https://doi.org/10.1097/cin.0000000000000646.

20. Tornivuori A, Tuominen O, Salanterä S, Kosola S. A systematic review on randomised controlled trials: coaching elements of digital services to support chronically ill adolescents during transition of care. J Adv Nurs. 2020;76:1293-306. https://doi.org/10.1111/jan.14323.

21. Ofcom. Children and parents: media use and attitudes report 2019, www.ofcom.org.uk/research-and-data/media-literacy-research/childrens/children-and-parents-media-use-and-attitudes-report-2019; 2020 [accessed 17 May 2021].

22. Dorgeat E, Adeleye A, Lifford K, Edwards A. Technological interventions to improve healthcare communication for children with long-term conditions: a systematic review and meta-analysis of randomised controlled trials. PROSPERO: International prospective register of systematic reviews. 2020. ID: CRD42020221977.

23. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA. Cochrane Handbook for Systematic Reviews of Interventions version 6.2, www.training.cochrane.org/handbook; 2021 [accessed 17 May 2021].

24. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. https://doi.org/10.1136/bmj.n71.

25. McHugh ML. Interrater reliability: the kappa statistic. Biochem Med. 2012;22(3):276-82.

26. Clarivate Analytics. EndNote X9.3.3, https://endnote.com; 2020 [accessed 17 May 2021].

27. Microsoft Corporation. Microsoft Excel, https://office.microsoft.com/excel; 2016 [accessed 17 May 2021].

28. Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ. 2019;366:I4898. https://doi.org/10.1136/bmj.I4898.

29. Popay J, Roberts H, Sowden A, Petticrew M, Arai L, Rodgers M et al. Guidance on the conduct of narrative synthesis in systematic reviews, www.lancaster.ac.uk/media/lancaster-university/content-assets/documents/fhm/dhr/chir/NSsynthesisguidanceVersion1-April2006.pdf; 2006 [accessed 17 May 2021].

30. Review Manager (RevMan) [Computer program]. Version 5.4. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration; 2014.

31. GRADE Working Group. Grading quality of evidence and strength of recommendations. BMJ. 2004;328:1490. https://doi.org/10.1136/bmj.328.7454.1490.

32. Bernier A, Fedele D, Guo Y, Chavez S, Smith MD, Warnick J et al. New-onset diabetes educator to educate children and their caregivers about diabetes at the time of diagnosis: usability study. JMIR Diabetes. 2018;3:e10. https://doi.org/10.2196/diabetes.9202.

33. Brown SJ, Lieberman DA, Gemeny BA, Fan YC, Wilson DM, Pasta DJ. Educational video game for juvenile diabetes: results of a controlled trial. Med Inform. 1997;22:77-89. https://doi.org/10.3109/14639239709089835.

34. Dragone MA, Bush PJ, Jones JK, Bearison DJ, Kamani S. Development and evaluation of an interactive CD-ROM for children with leukaemia and their families. Patient Educ Couns. 2002;46:297-307. https://doi.org/10.1016/S0738-3991(01)00166-5.

35. Guendelman S, Meade K, Benson M, Chen YQ, Samuels S. Improving asthma outcomes and self-management behaviors of inner-city children. Arch Pediatr Adolesc Med. 2002;156:114-20. https://doi.org/10.1001/archpedi.156.2.114.

36. Han Y, Spezia Faulkner M, Fritz H, Fadoju D, Muir A, Abowd GD et al. A pilot randomized trial of text-messaging for symptom awareness and diabetes knowledge in adolescents with type 1 diabetes. J Pediatr Nurs. 2015;30:850-61. https://doi.org/10.1016/j.pedn.2015.02.002.

37. Homer C, Susskind O, Alpert HR, Owusu C, Schneider L, Rappaport LA et al. An evaluation of an innovative multimedia educational software program for asthma management: report of a randomized, controlled trial. Pediatrics. 2000;106:210-5.

38. Huss M, Winkelstein M, Nanda J, Naumann PL, Sloand ED and Huss RW. Computer game for inner-city children does not improve asthma outcomes. J Pediatr Health Care. 2003;17:72-8. https://doi.org/10.1067/mph.2003.28.

39. Jan RL, Wang JY, Huang MC, Tseng SM, Su HJ and Liu LF. An internet-based interactive telemonitoring system for improving childhood asthma outcomes in Taiwan. Telemed J E Health. 2007;13;257-68. https://doi.org/10.1089/tmj.2006.0053.

40. Johnson KB, Patterson BL, Ho YX, Chen Q, Nian H, Davison CL et al. The feasibility of text reminders to improve medication adherence in adolescents with asthma. J Am Med Inform Assoc. 2016;23:449-55. https://doi.org/10.1093/jamia/ocv158.

41. Jones JK, Kamani SA, Bush PJ, Hennessy KA, Marfatia A and Shad AT. Development and evaluation of an educational interactive CD-ROM for teens with cancer. Pediatr Blood Cancer. 2010;55:512-9. https://doi.org/10.1002/pbc.22608.

42. Joseph CL, Ownby DR, Havstad SL, Saltzgader J, Considine S, Johnson D et al. Evaluation of a web-based asthma management intervention program for urban teenagers: reaching the hard to reach. J Adolesc Health. 2013;52:419-26. https://doi.org/10.1016/j.jadohealth.2012.07.009.

43. Knox E, Glazebrook C, Randell T, Leighton P, Guo B, Greening J et al. SKIP (Supporting Kids with diabetes In Physical activity): Feasibility of a randomised controlled trial of a digital intervention for 9-12 year olds with type 1 diabetes mellitus. BMC Public Health. 2019;19:371. https://doi.org/10.1186/s12889-019-6697-1.

44. Krishna S, Francisco BD, Balas EA, König P, Graff GR, Madsen RW. Internet-enabled interactive multimedia asthma education program: a randomized trial. Pediatrics. 2003;111:503-10. https://doi.org/10.1542/peds.111.3.503.

45. McPherson AC, Glazebrook C, Forster D, James C, Smyth A. A randomized, controlled trial of an interactive educational computer package for children with asthma. Pediatrics. 2006;117:1046-54. https://doi.org/10.1542/peds.2005-0666.

46. Ritterband LM, Cox DJ, Walker LS, Kovatchev B, McKnight L, Patel K et al. An internet intervention as adjunctive therapy for pediatric encopresis. J Consult Clin Psychol. 2003;71:910-7. https://doi.org/10.1037/0022-006X.71.5.910.

47. Rubin DH, Leventhal JM, Sadock RT, Letovsky E, Schottland P, Clemente I et al. Educational intervention by computer in childhood asthma: a randomised clinical trial testing the use of a new teaching intervention in childhood asthma. Pediatrics. 1986;77:1-10.

48. Tutar Güven S, Isler Dalgiç A, Duman Ö. Evaluation of the efficiency of the web-based epilepsy education program (WEEP) for youth with epilepsy and parents: a randomised controlled trial. Epilepsy Behav. 2020:111:107142. https://doi.org/10.1016/j.yebeh.2020.107142.

49. Wiecha JM, Adams WG, Rybin D, Rizzodepaoli M, Keller J and Clay JM. Evaluation of a web-based asthma self-management system: a randomised controlled pilot trial. BMC Pulm Med. 2015;15:17. https://doi.org/10.1186/s12890-015-0007-1.

50. Yun TJ, Young Jeong H, Hill TD, Lesnick B, Brown R, Abowd GD et al. Using SMS to provide continuous assessment and improve health outcomes for children with asthma. IHI '12. 2012:621-30. https://doi.org/10.1145/2110363.2110432.

51. Jones CL, Jensen JD, Scherr CL, Brown NR, Christy K, Weaver J. The Health Belief Model as an explanatory framework in communication research: exploring parallel, serial, and moderated mediation. Health Commun. 2015;30:566-76. https://doi.org/10.1080/10410236.2013.873363.

52. Bell J, Condren M. Communication strategies for empowering and protecting children. J Pediatr Pharmacol Ther. 2016;21:176-84. https://doi.org/10.5863/1551-6776-21.2.176.

53. Lefcourt HM, Wallston KA, Strudler Wallston B. Research with the Locus of Control Construct. 1st ed. Academic Press; 1981.

54. Brincks AM, Feaster DJ, Burns MJ, Mitrani VB. The influence of health locus of control on the patient-provider relationship. Psychol Health Med. 2010;15:720-8. https://doi.org/10.1080/13548506.2010.498921.

55. Free C, Phillips G, Watson L, Galli L, Felix L, Edwards P et al. The effectiveness of mobile-health technologies to improve health care service delivery processes: a

systematic review and meta-analysis. PLoS Med. 2013;10:e1001363. https://doi.org/10.1371/journal.pmed.1001363.

56. COMET Initiative. Core outcome measures in effectiveness trials, www.comet-initiative.org; [accessed 17 May 2021].

Table 1: Study Characteristics

Author Year	**Location**	**Characteristics** *Sample size, ages, LTC, HCP*	**Control (C)**	**Intervention (I)**	**Aim of intervention** *Conceptual model used?*	**Time period** *Exposure time, follow-up (FU)*	**Outcome measures**	**Results** *p value reported as comparison between intervention and control groups*	**Comments** *Risk of bias, limitations*
Bernier et al. 2018	Florida, USA	N = 16 4-15 years Type 1 diabetes Diabetes nurses	Standard diabetes education	Standard diabetes education, plus new-onset diabetes educator web application	To facilitate and foster diabetes knowledge acquisition and retention, aimed at expanding and enhancing standard diabetes self-management education	I: no comment C: 3-4 hours FU: no comment	Knowledge♦ (DKT2)	Knowledge improvement for both I and C, no significant difference between groups (p=0.213)	*High risk of bias* Lim: usability study, small sample size, few outcomes reported
Brown et al. 1997	California, USA	N = 59 8-16 years Type 1 diabetes Paediatric endocrinologists	Entertainment video game containing no diabetes-related content	*'Packy & Marlon'* diabetes self-care interactive video game (Nintendo)	To improve a young person's self-confidence, ability and motivation to undertake rigorous self-care necessary to control insulin-dependent diabetes *Yes: based on theoretical framework designed to enhance mediating factors, e.g. self-concepts, social support, knowledge*	I: 6m access FU: 3m, 6m	Knowledge♦ (Q); urgent physician visits♦; HbA_{1c}♦; self-care (Q); self-efficacy	Improved self-care behaviours (p=0.003)† and communication with parents (p=0.025)† No significant improvement for knowledge (p=0.64), urgent physician visits (p=0.08), HbA_{1c} (p=0.67) or self-efficacy (p=0.07)	*Some concerns about risk of bias* Lim: no comment about blinding, baseline characteristics or loss to follow-up
Dragone et al. 2002	District of Colombia, Virginia & Ohio, USA	N = 41 4-11 years Leukaemia Paediatric oncologists and nurse specialists	Standard care ('You and Leukaemia' book)	*'Kidz with Leukaemia: A Space Adventure'* interactive CD-ROM	To educate children about their cancer, to know more about their illness and feel more in control of their health *Yes: development prompted through social learning theory*	I/C: 3m access FU: 3m	Knowledge (Q); health locus of control♦ (LCHLC)	More internal health locus of control (p=0.004)† No improvement between groups for knowledge (p=0.096) – I had more detailed narratives about leukaemia events	*Some concerns about risk of bias* Lim: small sample sizes, interviewers not blinded
Guendelman et al. 2002	California, USA	N = 134 8-16 years Asthma Nurse coordinator	Asthma diary (symptom, lung function and medication log)	*'Health Buddy'* interactive device to assess and monitor asthma symptoms	For children to acquire knowledge about asthma and symptom recognition and receive immediate feedback on their decisions and behaviours	I: 10 questions per day FU: 6w, 12w	Health service use; lung function (PEFR); activity limitations; asthma symptoms; school absence; medication compliance	Improvements in activity (p=0.03)†, lung function (p=0.01)† and urgent calls (p=0.05)† No improvement between groups for coughing/wheezing symptoms, trouble sleeping, school absence, emergency visits or medication compliance	*Some concerns about risk of bias* Inner city children Lim: loss to follow-up over 12w period, diary responses inaccurate
Han et al. 2015	Georgia, USA	N = 30 10-17 years Type 1 diabetes Nurse practitioners and diabetes educators	Standard care	Text-messaging system with symptoms awareness (S group) +/- knowledge (SK group) messages	To challenge children's perceived severity of disease, knowledge and cue to action to influence health behaviour *Yes: Health Belief Model, by challenging children's symptom awareness and knowledge*	I: daily text for 3-4m FU: 3-4m	HbA_{1c}♦; quality-of-life (PAID, DQOLY)	Non-significant reductions in HbA1c (p=0.666) Quality-of-life: 'worry' subscale decreased in I and increased in C, intervention had reduced 'perceived impact of diabetes' (p=0.008)†	*High risk of bias* Only adolescents with mobile phone and unlimited data plans could participate Lim: small sample size, one diabetes clinic used
Homer et al. 2000	Massachusetts, USA	N = 137 3-12 years Asthma Physicians	Asthma education book and non-educational	*'Asthma Control'* educational computer programme	To provide patients with the substantive knowledge required for good asthma care and to provide a simulated environment in which children and their families could	I/C: 3 x 30-60 mins FU: 10m	Knowledge (Q); emergency visits; symptom severity (CHQ), functional	Improved knowledge (p<0.001)† All other outcomes improved for both groups, not significant between groups	*Some concerns about risk of bias* Use of computer only in clinic may have diminished effect of repetitive learning

			computer game		safely gain experience with asthma-related decision-making		status; number of triggers/allergens		Lim: only 61% participants attended >1 session
Huss et al. 2003	Maryland, USA	N = 148 7-12 years Asthma Physicians	Standard education (written materials) and unrelated computer programme	*'Wee Willie Wheezie'* computer-assisted instructional game	To educate children with asthma in their homes about allergen avoidance *Yes: PRECEDE-PROCEED model guided development and concepts from developmental, social support and learning theories used*	I/C: 20 mins FU: 12w	Knowledge♦ (Q); lung function (FEV_1, PEFR); asthma symptoms; quality-of-life (PAQLQ)	No significant changes between groups in all outcomes Asthma knowledge high in both groups at baseline	*Some concerns about risk of bias* Participants lost to follow-up were younger (p<0.02) Lim: unable to accurately time exposure to intervention, high loss to follow-up
Jan et al. 2007	Tainan, Taiwan	N = 196 6-12 years Asthma Nurses	Standard care (written asthma diary with management instructions)	*'Blue Angel for Asthma Kids'* Internet-based interactive educational programme	To monitor daily allergic and asthmatic symptoms by asthmatic children, provide information for an action plan, and enhance compliance of daily allergy and asthma control	I/C: daily entry for 12w FU: 12w	Knowledge (Q); lung function♦ (PEFR); symptoms; quality-of-life (PAQLQ); medication adherence; asthma control (PACT)	Improved knowledge (p<0.05)†, lung function (p=0.01)†, quality-of-life (p<0.05)†, daytime and nighttime symptoms (p=0.009, p=0.028)†, monitoring (p=0.017)†, adherence (p<0.05)† and asthma control (p<0.05)†	*Some concerns about risk of bias* Lim: unclear whether all children interacted
Johnson et al. 2016	USA	N = 98 12-17 years Asthma Paediatricians	Standard care (action plan lists)	*'MyMediHealth'* website and text message-based reminder system	To help manage medications and dosing reminders	I/C: 3w access FU: 3w	Medication adherence; asthma control (ACT); self-efficacy (CASES); quality-of-life (PAQLQ)	Improved medication adherence (p=0.011)†, self-efficacy (p=0.016)† and quality-of-life (p=0.037)† No improvement between groups for asthma control (p=0.728)	*Some concerns about risk of bias* Lim: short follow-up, usability problems (13% never interacted with int, disproportionately African-American participants)
Jones et al. 2010	California, District of Colombia, Pennsylvania & New York, USA	N = 71 12-18 years Cancer Paediatric oncologists and nurses	Educational handbook with similar contents	Interactive multimedia cancer CD-ROM	To educate adolescents (learn and retain information) about their cancer	I/C: 3m access FU: 3m	Knowledge♦ (Q); health locus of control♦ (MHLC); quality-of-life (POQOLS); coping style (KidCOPE); self-efficacy (Q)	More internal health locus of control (p=0.016)† No improvement between groups for knowledge, quality-of-life, coping style or self-efficacy	*Some concerns about risk of bias* Participants wanted CD at diagnosis when they felt more motivated Lim: small sample size, unable to determine exposure time
Joseph et al. 2013	Michigan, USA	N = 422 14-17 years Asthma Physician	Generic asthma information websites	*'Puff City'* web-based asthma intervention	For children to gain better control of their asthma by changing negative behaviours related to asthma self-regulation and management *Yes: theoretical models and approaches to behaviour change used (e.g. Health Belief Model, Attribution Theory, Motivational Interviewing)*	I/C: 4 x 15-30 mins FU: 12m	Hospital visits; hospitalisations; asthma symptoms; restricted activity; school absence	Improved symptom-days (p=0.006)† and restricted activity days (p=0.01)† No improvement in healthcare use, symptom-nights or school absence	*Low risk of bias* Good retention, 88.4% completed all four sessions Lim: only self-reported measures, subjective
Knox et al. 2019	Nottingham, UK	N = 49 9-12 years Type 1 diabetes Consultant physicians	Standard care	Standard care, plus STAK-D website	To increase participants' self-efficacy for diabetes self-management (e.g. confidence around management)	I: 6m access FU: 8w, 6m	HbA_{1c}♦; insulin dose; body mass index; fear of hypoglycaemia; perceived health	No significant differences between groups at 6m Clinician communication score better in intervention, but no significant difference (p=0.3 at 8w, p=0.36 at 6m)	*Some concerns about risk of bias* Lim: poor engagement with intervention (33.3%) despite

							(CHQ); physical activity; clinician communication (Q)		reminders, ethnic minority groups underrepresented
Krishna et al. 2003	Missouri, USA	N = 97 7-17 years Asthma Paediatric pulmonary physicians	Standard care (self-management education)	Self-management education, plus Interactive Multimedia Programme for Asthma Control and Tracking (IMPACT)	To improve children's knowledge and health status and decrease use of healthcare resources	I: 1 hour 20 mins C: 3 x 1.5 hours FU: 3m, 12m	Knowledge♦ (Q); health services utilisation♦; asthma symptoms; quick-relief medication use	Improved knowledge ($p<0.01$)† significantly correlated with fewer urgent physician visits ($r=0.37$, $p=0.01$)† and less frequent use of quick-relief medications ($r=0.30$, $p<0.05$)† Decreased asthma symptoms $p<0.01$)†, number of emergency visits ($p<0.01$)† and need for medication ($p<0.01$)†	*Low risk of bias* Lim: self-reported data may be inaccurate, participants from one clinic (primarily rural)
McPherson et al. 2006	East Midlands, UK	N = 101 7-14 years Asthma Respiratory consultants	Asthma information booklet only	Asthma information booklet, plus *'The Asthma Files'* interactive CD-ROM	To increase children's knowledge, have a more internal locus of control and improved clinical outcomes	I: 90 mins FU: 1m, 6m	Knowledge♦ (AKA); locus of control♦ (CALOC); lung function♦ (FEV_1, PEFR); oral steroid use; hospitalisations; school absence	1m FU: improved knowledge ($p=0.001$)† and more internal locus of control ($p=0.007$)†, no significant improvement in lung function, steroid use or hospitalisations 6m FU: reduced steroid use (OR 2.22) and school absence (OR 2.14)	*Some concerns about risk of bias* Lung function over 90% at baseline for both groups Lim: time spent with CD-ROM and booklet not monitored
Ritterband et al. 2003	Virginia & Tennessee, USA	N = 24 6-12 years Encopresis Primary care physicians	Standard care	Standard care, plus *'U-CAN-POOP-*TOO' Internet-based enhanced toilet training	To provide the components of enhanced toilet training in a child-focused engaging manner	I: 3w access FU: 3w	Knowledge♦ (EKQ); soiling accidents; other bowel-specific problems (e.g. toilet avoidance)	I and C had similar improvements in knowledge and bowel problems Reduced soiling accidents ($p=0.018$)†, increased toilet defecation ($p=0.021$)† and increase in unprompted trips to the toilet ($p=0.109$)	*Low risk of bias* Average of 14 visits to intervention during study Lim: unsure of nature of care in control group, short follow-up, small sample size
Rubin et al. 1986	Connecticut, USA	N = 65 7-12 years Asthma Paediatricians	Verbal asthma management instructions and routine computer games	*'Asthma* Command' interactive computer game	To emphasise four basic principles in the management of childhood asthma: (1) the recognition of symptoms and allergens, (2) the appropriate use of medications, (3) the appropriate use of the emergency room and physician's office, and (4) the encouragement of school attendance	I/C: 6 x 40 mins FU: 10m	Knowledge♦ (PKAQ); health locus of control♦ (CHLC); self-esteem (Q); acute visits♦; school absence	Improvement in knowledge ($p<0.001$)† ,behaviour-related asthma management ($p<0.008$)† and acute visits ($p<0.13$)	*Low risk of bias* Lim: small sample size, aspects of game missed (e.g. acute care) if participants were good enough at managing asthma within the game
Tutar Güven et al. 2020	Turkey	N = 70 9-18 years Epilepsy Paediatric neurologists	Physician appointment	Web-based epilepsy education programme (WEEP)	To improve the level of knowledge of epilepsy, seizure self-efficacy, attitude toward epilepsy and e-health literacy of youth with epilepsy	I: 12w access FU: 12w	Knowledge♦ (EKT); seizure self-efficacy (SSES-C); attitudes (CATIS); e-health literacy (eHEALS)	Intervention had significant increase in all outcomes from pre- to post-test ($p<0.05$)	*Some concerns about risk of bias* Lim: only participants with internet access were included, short follow-up (12w)
Wiecha et al. 2015	Massachusetts, USA	N = 58 9-17 years Asthma	Standard care	*'BostonBreathes'*, interactive website and HCP-patient platform	To improve adherence to asthma controller medications among children with asthma through education, self-monitoring and rewards	I: 6m access FU: 6m	Knowledge♦ (Q); medication compliance; symptoms; school	Improvement in knowledge ($p=0.03$)† between groups, improvement in wheezing symptom for both groups (I	*Some concerns about risk of bias* Lim: small sample size, two intervention groups

		Family physicians, paediatricians and nurse practitioners			*Yes: based on social cognitive theory and e-health behaviour management model*		absence; acute asthma visits♦	p=0.03, C p=0.004), no difference between groups Improvement in medication compliance only for intervention subgroup with previously low compliance (p=0.01)	combined during study (+/- discussion board)
Yun et al. 2012	Georgia, USA	N = 30 10-18 years Asthma Physicians	Standard care	Text-messaging service with asthma survey (Query group) +/- knowledge questions (QK group)	To support communication between the patient and physician by sending questions about asthma management and asthma knowledge *Yes: Health Belief Model guides framework*	Query: text every 2 days for 3-4m QK: text every day for 3-4m FU: 3-4m	Knowledge♦ (Q); lung function♦ (FEF); quality-of-life (PAQLQ)	No significant difference between groups for any outcomes Improvement in QK group lung function compared with Query (p=0.007) Improvement in QK group for knowledge compared with Query and control (p=0.026)	*Some concerns about risk of bias* Lim: small sample size, large differences in follow-up intervals (range 94-151 days), literacy levels aimed too high for some participants

† Significant difference between intervention and control groups ($p < 0.05$)

♦ Included in meta-analysis Lim: limitations

Knowledge measures: AKA (Asthma Knowledge Assessment); DKT2 (Diabetes Knowledge Test 2); EKT (Epilepsy Knowledge Test); EKQ (Encopresis Knowledge Questionnaire); PKAQ (Parcel Knowledge of Asthma Questionnaire); Q (non-validated, per-protocol questions)
Locus of control measures: CALOC (Children's Asthma Locus Of Control); (L)CHLC ((Leukaemia) Children's Health Locus of Control); MHLC (Multidimensional Health Locus of Control)
Condition control measures: HbA_{1c} (glycated haemoglobin); (P)ACT ((Paediatric) Asthma Control Test); FEF (Forced Expiratory Flow); FEV_1 (Forced Expiratory Volume in the first second); PEFR (Peak Expiratory Flow Rate)
Quality-of-life measures: DQOLY (Diabetes Quality-of-life For Youth); PAID (Problem Areas In Diabetes); PAQLQ (Paediatric Asthma Quality-of-life Questionnaire); POQOLS (Paediatric Oncology Quality-of-life Scale)
Other measures: CASES (Child Asthma Self-Efficacy Scale); CATIS (Child Attitude Toward Illness Scale); CHQ (Child Health Questionnaire); eHEALS (e-Health Literacy Scale); SSES-C (Seizure Self-Efficacy Scale for Children; Q (non-validated, per-protocol questions)

Box 1

Eligibility criteria for study selection

	Inclusion criteria	Exclusion criteria
Population	Children: aged up to 18 years with a diagnosis of a long-term condition Healthcare professionals: trained members of the healthcare team who contribute to the holistic care of the patient	Participants aged 19 years and over, or insufficient data regarding participant age Individuals who do not play a trained role in the medical care of the patient
Intervention	A specific intervention that aimed to improve communication between healthcare professionals and the patient, using the assistance of technology	Interventions directed at or interacted with by only the healthcare professional or the patient's caregiver; forms part of the patient's treatment; or where the technology was used only to facilitate the logistics of the consultation
Study design	Randomised controlled trials	Study not a randomised controlled trial
Outcome	Effectiveness of intervention examined using one or more of: cognitive, affective, physiological or health outcomes	Effectiveness of intervention not measured; only thoughts, experiences or feedback of the intervention reported

Figure 1

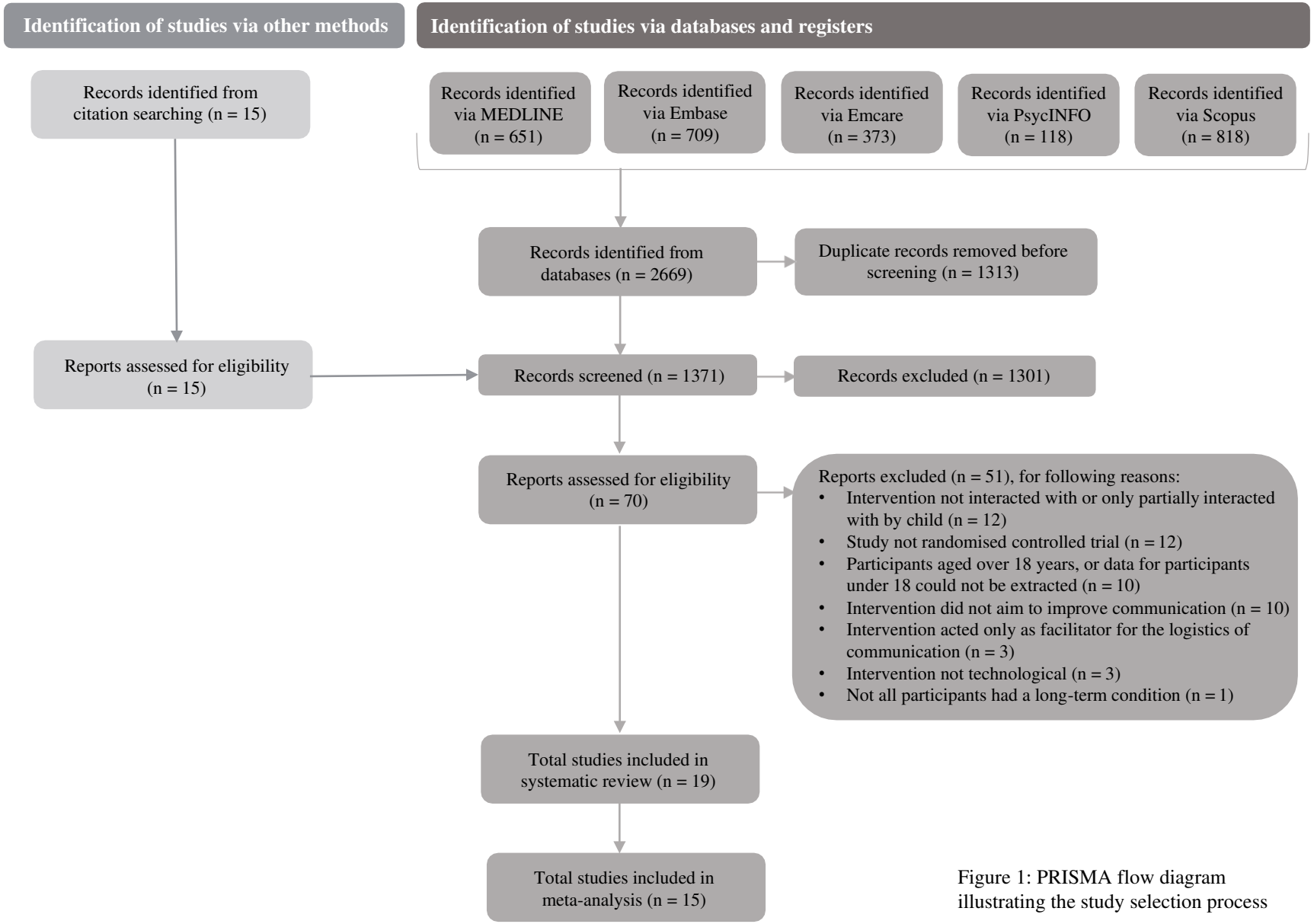


Figure 1: PRISMA flow diagram illustrating the study selection process

Figure 2

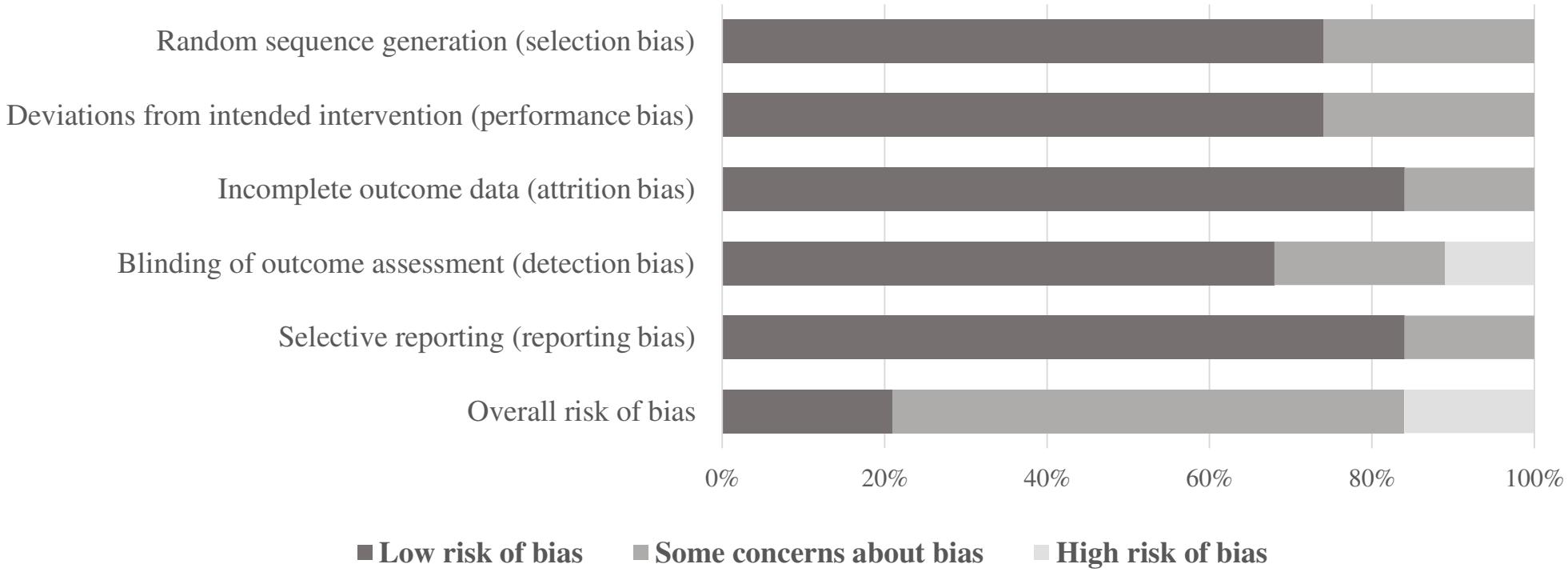


Figure 2: Risk of bias assessment across 19 included studies

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bernier et al. 2018	3.88	3.379	8	1.88	2.262	8	5.8%	0.66 [-0.36, 1.67]
Brown et al. 1997	1.16	3.23	31	0.68	4.54	28	10.2%	0.12 [-0.39, 0.63]
Huss et al. 2003	0.5	1.788	56	0.3	2.174	45	11.4%	0.10 [-0.29, 0.49]
Jones et al. 2010	-0.06	3.106	35	1.55	3.106	30	10.3%	-0.51 [-1.01, -0.02]
Krishna et al. 2003	10	6.99	25	4.44	5.49	27	9.6%	0.88 [0.30, 1.45]
McPherson et al. 2006	3.97	3.604	50	1.55	3.45	51	11.3%	0.68 [0.28, 1.08]
Ritterband et al. 2003	3.83	2.943	12	3.78	4.202	12	7.4%	0.01 [-0.79, 0.81]
Rubin et al. 1986	14.4	13.4	29	2	12.7	25	9.6%	0.93 [0.37, 1.50]
Tutar Güven et al. 2020	0.36	0.343	35	-0.01	0.326	34	10.2%	1.09 [0.58, 1.60]
Wiecha et al. 2015	5	61.537	28	-1	41.155	14	8.8%	0.11 [-0.54, 0.75]
Yun et al. 2012	1	1.7348	10	0.8	1.518	5	5.4%	0.11 [-0.96, 1.19]
Total (95% CI)			**319**			**279**	**100.0%**	**0.39 [0.07, 0.71]**

Heterogeneity: $Tau^2 = 0.19$; $Chi^2 = 33.68$, df = 10 (P = 0.0002); $I^2 = 70\%$

Test for overall effect: Z = 2.38 (P = 0.02)

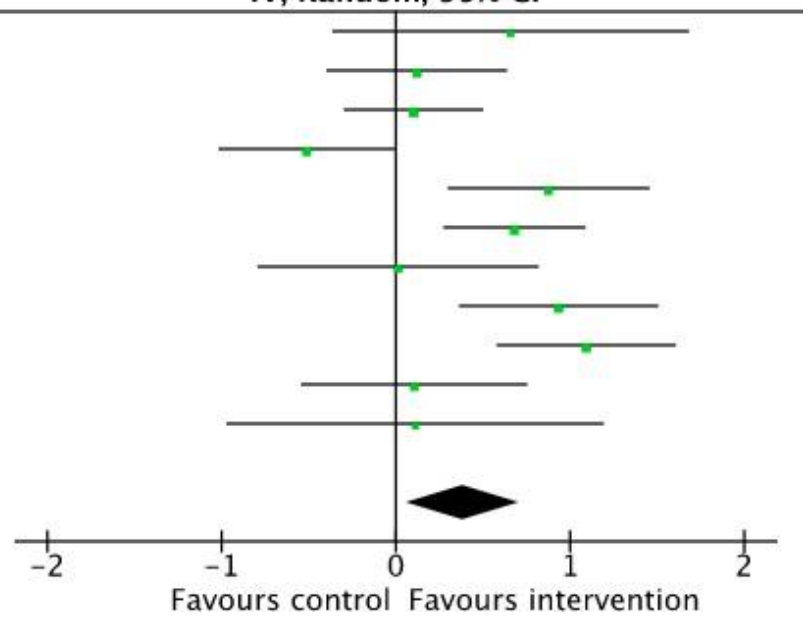


Figure 3: Forest plot for knowledge outcome

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dragone et al. 2002	1.524	2.8346	15	-0.81	3.1294	16	11.9%	0.76 [0.03, 1.49]
Jones et al. 2010	3.86	4.716	35	0.97	5.243	30	25.7%	0.58 [0.08, 1.07]
McPherson et al. 2006	0.82	2.101	50	-0.19	1.73	51	40.4%	0.52 [0.12, 0.92]
Rubin et al. 1986	1.3	6.1	29	-0.9	10.7	25	22.1%	0.25 [-0.28, 0.79]
Total (95% CI)			**129**			**122**	**100.0%**	**0.50 [0.25, 0.76]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.39$, df = 3 (P = 0.71); $I^2 = 0\%$

Test for overall effect: Z = 3.92 (P < 0.0001)

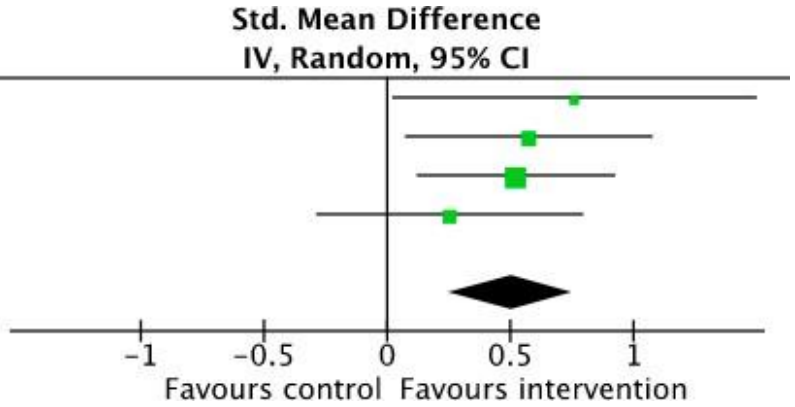


Figure 4: Forest plot for health locus of control outcome

Declaration of Competing Interest

Effectiveness of technological interventions to improve healthcare communication with children with long-term conditions: a systematic review and meta-analysis of randomised controlled trials

Authors: Emma Dorgeat, Ayowade Adeleye, Dr Kate J Lifford, Professor Adrian Edwards

Declarations of interest: none.

Supplementary File 1

PRISMA checklists

Supplementary Material 1.1: PRISMA 2020 item checklist

Section and topic	Item number	Checklist item	Section where item is reported
Title			
Title	1	Identify the report as a systematic review.	Cover page
Abstract			
Abstract	2	See the PRISMA 2020 abstract checklist (Table A2).	Abstract
Introduction			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	1.1
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	1.2
Methods			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	2.4, Suppl. 2
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	2.2
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	2.3, Suppl. 2
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	2.4
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	2.5
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	2.7, 2.8

	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	2.5
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	2.6
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	2.8
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	2.8
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	2.8, Suppl. 3
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	2.8
	13d	Describe any methods used to synthesise results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	2.8
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	2.8
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesised results.	2.8
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	2.6
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	2.8
Results			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	3.1, Figure 1
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Suppl. 4
Study characteristics	17	Cite each included study and present its characteristics.	3.2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	3.3, Figure 2

Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Table 1
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	3.4, Suppl. 5
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	3.6, Suppl. 7
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	3.6, Suppl. 7
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesised results.	3.6, Suppl. 7
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	3.6, Suppl. 8
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	3.6, Suppl. 6
Discussion			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	4.1
	23b	Discuss any limitations of the evidence included in the review.	4.1
	23c	Discuss any limitations of the review processes used.	4.1
	23d	Discuss implications of the results for practice, policy, and future research.	4.1, 4.3
Other information			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	2.1
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	2.1, Ref. 22
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	2.8
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Funding
Competing interests	26	Declare any competing interests of review authors.	Declaration of competing interest
Availability of data, code, and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Ref. 22-31

Supplementary Material 1.2: PRISMA 2020 abstract checklist

Section and topic	Item number	Checklist item	Location where item is reported
Title			
Title	1	Identify the report as a systematic review.	Cover page
Background			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Objective
Methods			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Methods
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Methods
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	Methods
Synthesis of results	6	Specify the methods used to present and synthesise results.	Methods
Results			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Results
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Results
Discussion			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision).	Conclusion
Interpretation	10	Provide a general interpretation of the results and important implications.	Conclusion
Other			
Funding	11	Specify the primary source of funding for the review.	No funding
Registration	12	Provide the register name and registration number.	Methods

Supplementary File 2

Eligibility criteria for study selection

	Inclusion criteria	Exclusion criteria
Population	Children – patients aged up to 18 years with a diagnosis of a long-term condition (lasting over 6 months) which cannot be cured but can be controlled by medication and therapies Healthcare professional – a trained member of the healthcare team who contributes to the holistic care of the patient (e.g. general practitioner, specialty doctor, practice nurse, specialist nurse, physiotherapist, speech therapist)	Children: • Patients aged 19 years and over or insufficient data regarding participant age • Studies where the children's data could not be extracted from data pertaining to older patients not included in this review Healthcare professional: • An individual who does not play a trained role in the medical care of the patient
Intervention	A specific intervention that aimed to improve communication (the exchange of information) between healthcare professionals and the patient, using the assistance of technology The technology must be interacted with by the child with a long-term condition, e.g. child actively plays with/chooses elements of the intervention	An intervention directed at or interacted with by only the healthcare professional or the patient's caregiver An intervention that forms part of the patient's treatment or involves changing the treatment provided (e.g. cognitive behaviour therapy, physical therapy, medication administration device) An intervention where the technology was used only to facilitate the logistics of the consultation (e.g. telephone appointment, videoconferencing)
Comparison	Randomised controlled trials (RCTs) comparing interventions with an inactive control (standard care) or active control (intervention variant) Pilot and usability RCTs if fulfilling eligibility criteria	Study design not an RCT Studies describing the need for such an intervention or an intervention already used in practice, or assessing cost-effectiveness
Outcome	Effectiveness of intervention through examining one or more of the following measures: • Cognitive – e.g. knowledge about condition • Affective – e.g. emotions and attitudes towards condition, patient confidence surrounding self-management and decision-making • Physiological – e.g. biomedical parameters • Health – e.g. symptoms and relapses, use of healthcare services	Effectiveness of intervention not measured Only thoughts, experiences or feedback of the intervention reported

MEDLINE search strategy

MEDLINE was searched using the Ovid interface on 14th May 2021

#	Searches	Results	#	Searches	Results
1	exp Child Health/	3,400	78	"family doctor*".mp.	4,821
2	exp Child Health Services/	24,789	79	specialist*.mp.	104,870
3	exp Pediatrics/	59,961	80	nurs*.mp.	755,399
4	paediatric*.mp.	72,742	81	physiotherap*.mp.	28,608
5	pediatric*.mp	376,548	82	"physical therap*".mp.	57,767
6	child*.mp.	2,525,935	83	"speech therap*".mp.	8,810
7	teen*.mp.	32,127	84	"speech and language".mp.	11,086
8	adolescen*.mp.	2,170,930	85	(outpatient* adj2 clinic*).mp.	52,324
9	"young pe*".mp.	34,640	86	64 or 65 or 66 or 67 or 68 or 69 or 70 or 71 or 72 or 73 or 74 or 75 or 76 or 77 or 78 or 79 or 80 or 81 or 82 or 83 or 84 or 85	1,862,888
10	"young adult*".mp.	983,637	87	exp Educational Technology/	111,108
11	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10	4,175,852	88	exp Internet-Based Intervention/	530
12	exp Chronic Disease/	268,255	89	exp Mobile Applications/	7,718
13	exp Asthma/	131,250	90	exp "Play and Playthings"/	15,079
14	exp Cystic Fibrosis/	36,272	91	exp Text Messaging/	3,407
15	exp Heart Defects, Congenital/	156,273	92	exp Social Media/	9,974
16	exp Diabetes Mellitus/	442,495	93	exp Electronic Mail/	2,767
17	exp Epilepsy/	114,837	94	exp Computer Simulation/	251,729
18	exp Arthritis/	267,492	95	exp Multimedia/	1,981
19	exp Neoplasms/	3,458,526	96	exp Telemedicine/	34,240
20	exp Anemia, Sickle Cell/	23,165	97	technolog*.mp.	592,194
21	exp Inflammatory Bowel Diseases/	84,079	98	computer*.mp.	842,854
22	exp Celiac Disease/	20,418	99	internet*.mp.	111,179
23	exp Cerebral Palsy/	21,280	100	application*.mp.	1,307,861
24	exp Muscular Dystrophies/	27,377	101	video*.mp.	184,631
25	exp Depression/	127,186	102	game*.mp.	67,509
26	exp Anxiety/	91,374	103	text*.mp.	174,552
27	"chronic disease*".mp.	322,505	104	web*.mp.	181,979
28	(chronic adj2 condition*).mp.	37,766	105	e-mail*.mp.	8,828
29	"chronic illness*".mp.	17,209	106	forum*.mp.	16,333
30	"long term disease*".mp.	3,463	107	"social media".mp.	19,772
31	(long term adj2 condition*).mp.	4,386	108	Facebook.mp.	4,369
32	"long term illness*".mp.	777	109	Instagram.mp.	817
33	asthma*.mp.	186,245	110	Snapchat.mp.	116
34	"cystic fibrosis".mp.	53,001	111	WeChat.mp.	468
35	congenital.mp.	363,203	112	Twitter.mp.	4,042
36	"heart disease*".mp.	249,569	113	WhatsApp.mp.	749
37	diabet*.mp.	735,810	114	"Tik Tok".mp.	4
38	epilep*.mp.	170,163	115	virtual.mp.	69,146
39	arthritis.mp.	229,909	116	multimedia.mp.	6,072
40	cancer*.mp.	1,942,745	117	software*.mp.	266,112
41	leukaemia*.mp.	37,835	118	telehealth.mp.	7,423
42	leukemia*.mp.	323,719	119	telemedicine.mp.	35,416
43	"sickle cell".mp.	29,856	120	mhealth.mp.	5,891

44	“inflammatory bowel disease*”.mp.	57,488	121	87 or 88 or 89 or 90 or 91 or 92 or 93 or 94 or 95 or 96 or 97 or 98 or 99 or 100 or 101 or 102 or 103 or 104 or 105 or 106 or 107 or 108 or 109 or 110 or 111 or 112 or 113 or 114 or 115 or 116 or 117 or 118 or 119 or 120	3,303,730
45	Crohn*.mp.	59,084	122	exp Randomized Controlled Trials as Topic/	530,763
46	“ulcerative colitis”.mp.	42,299	123	exp Random Allocation/	105,301
47	coeliac.mp.	8,256	124	exp Double-Blind Method/	164,070
48	celiac.mp.	34,386	125	exp Single-Blind Method/	30,134
49	“cerebral palsy”.mp.	28,769	126	exp Clinical Trials as Topic/	891,499
50	“muscular dystrophy”.mp.	26,271	127	exp Placebos/	38,095
51	depress*.mp.	571,342	128	“randomized controlled trial”.mp.	563,505
52	anxi*.mp.	268,363	129	“randomised controlled trial”.mp.	25,849
53	12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50 or 51 or 52	7,085,361	130	“clinical trial”.mp.	734,260
54	exp Communication/	321,497	131	clinical trial, phase i.pt.	21,567
55	exp Health Communication/	2,689	132	clinical trial, phase ii.pt.	34,747
56	exp Health Education/	250,123	133	clinical trial, phase iii.pt.	18,356
57	exp Patient Education as Topic/	87,029	134	clinical trial, phase iv.pt.	2,091
58	exp Health Information Exchange/	950	135	controlled clinical trial.pt.	94,148
59	exp Physician-Patient Relations/	73,905	136	randomized controlled trial.pt.	529,609
60	communicat*.mp.	445,289	137	multicenter study.pt.	293,662
61	educat*.mp.	1,081,500	138	clinical trial.pt.	528,703
62	interact*.mp.	1,784,608	139	(clinical adj trial*).tw.	398,265
63	54 or 55 or 56 or 57 or 58 or 59 or 60 or 61 or 62	3,398,738	140	((single* or double* or treb* or tripl*) adj (blind* or mask*)).tw.	180,002
64	exp Physicians/	149,696	141	placebo*.tw.	224,944
65	exp General Practitioners/	8,428	142	randomly allocated.tw.	30,947
66	exp Nurses/	90,272	143	(allocated adj2 random*).tw.	34,381
67	exp Physical Therapists/	2,159	144	randomly assigned.tw.	110,966
68	exp Speech Therapy/	6,479	145	(assigned adj2 random*).tw.	117,494
69	“healthcare professional*”.mp.	26,573	146	(randomized adj2 trial*).tw.	279,005
70	“health care professional*”.mp.	26,224	147	(randomized adj2 controlled*).tw.	215,899
71	HCP*.mp.	8,619	148	122 or 123 or 124 or 125 or 126 or 127 or 128 or 129 or 130 or 131 or 132 or 133 or 134 or 135 or 136 or 137 or 138 or 139 or 140 or 141 or 142 or 143 or 144 or 145 or 146 or 147	1,696,397
72	“healthcare worker*”.mp.	13,500	149	case report.tw.	334,120
73	“health care worker*”.mp.	14,906	150	letter/	1,135,011
74	doctor*.mp.	134,772	151	historical article/	363,508
75	physician*.mp.	591,827	152	149 or 150 or 151	1,815,873
76	“general practic*”.mp.	53,824	153	148 not 152	1,667,516
77	GP*.mp.	212,676	154	11 and 53 and 63 and 86 and 121 and 153	651

Supplementary File 3

Equations used to calculate difference in mean and standard deviation for meta-analysis

Mean difference	$\text{Mean}_{\text{change}} = \text{Mean}_{\text{final}} - \text{Mean}_{\text{baseline}}$
Correlation coefficient	$\text{Corr} = \dfrac{\text{SD}^2_{\text{baseline}} + \text{SD}^2_{\text{final}} - \text{SD}^2_{\text{change}}}{2 \times \text{SD}_{\text{baseline}} \times \text{SD}_{\text{final}}}$
Standard deviation difference	$\text{SD}_{\text{change}} = \sqrt{\text{SD}^2_{\text{baseline}} + \text{SD}^2_{\text{final}} - (2 \times \text{Corr} \times \text{SDbaseline} \times \text{SDfinal})}$

Supplementary File 4

Studies excluded following full-text screening

#	References	Reason for exclusion
1	Arman N, Tarakci E, Tarakci D, Kasapcopur O. Effects of video games-based task-oriented activity training (Xbox 360 Kinect) on activity performance and participation in patients with juvenile idiopathic arthritis: a randomized clinical trial. *American Journal of Physical Medicine & Rehabilitation*. 2019;98(3):174-181. doi: 10.1097/PHM.0000000000001001.	Intervention did not aim to improve communication *(acts as physical therapy)*
2	Balato N, Megna M, Di Costanzo L, Balato A, Ayala F. Educational and motivational support service: a pilot study for mobile-phone based interventions in patients with psoriasis. *British Journal of Dermatology.* 2013;168(1):201-205. doi: 10.1111/j.1365-2133.2012.11205.x.	Participants aged over 18 years, or data for participants under 18 could not be extracted
3	Bartholomew LK, Gold RS, Parcel GS, Czyewski DI, Sockrider MM, Fernandez M et al. Watch, Discover, Think, and Act: evaluation of computer-assisted instruction to improve asthma self-management in inner-city children. *Patient Education and Counseling.* 2000;39(2-3):269-280. doi: 10.1016/s0738-3991(99)00046-4.	Study not randomised controlled trial
4	Benoit C, Orbach D, Cyrille S, Belhous K, Minard-Colin V, Kadlub N et al. Head and neck tumours in children and adolescents: impact of a multidisciplinary tumor board. *Oral Oncology.* 2021;114:105145. doi: 10.1016/j.oraloncology.2020.105145.	Study not randomised controlled trial
5	Boon M, Calvo-Lerma J, Claes I, Havemans T, Asseiceira I, Bulfamente A et al. Use of a mobile application for self-management of pancreatic enzyme replacement therapy is associated with improved gastro-intestinal related quality of life in children with Cystic Fibrosis. *Journal of Cystic Fibrosis.* 2020;19(4):562-568. doi: 10.1016/j.jcf.2020.04.001	Study not randomised controlled trial
6	Cadario F, Binotti M, Brustia M, Mercandino F, Moreno G, Esposito S et al. Telecare for teenagers with type 1 diabetes: a trial. *Minerva Pediatrics.* 2007;59(4):299-305. PMID: 17947836.	Participants aged over 18 years, or data for participants under 18 could not be extracted *(participants aged 10-20 years)*
7	Chen LL, Lei YQ, Liu JF, Cao H, Yu XR, Chen Q. Application and effects of an early childhood education machine on analgesia and sedation in children after cardiothoracic surgery. *Journal of Cardiothoracic Surgery.* 2021;16(1):118. doi: 10.1186/s13019-021-01490-2.	Intervention did not aim to improve communication
8	Choi JY, Yi SH, Ao L, Tang X, Xu X, Shim D et al. Virtual reality rehabilitation in children with brain injury: a randomised controlled trial. *Developmental Medicine & Child Neurology.* 2021;63(4):480-487. doi: 10.1111/dmcn.14762.	Intervention did not aim to improve communication *(acts as physical therapy)*
9	Connelly M, Rapoff MA, Thompson N, Connelly W. Headstrong: a pilot study of a CD-ROM intervention for recurrent pediatric headache. *Journal of Pediatric Psychology.* 2006;31(7):737-747. doi: 10.1093/jpepsy/jsj003.	Intervention did not aim to improve communication
10	Davis MA, Quittner AL, Stack CM, Yang MC. Controlled evaluation of the STARBRIGHT CD-ROM program for children and adolescents with cystic fibrosis. *Journal of Pediatric Psychology.* 2004;29(4):259-267. doi: 10.1093/jpepsy/jsh026.	Intervention not interacted with or only partially interacted with by the child
11	Dexheimer JW, Abramo TJ, Arnold DH, Johnson K, Shyr Y, Ye F et al. Implementation and evaluation of an integrated computerized asthma management system in a pediatric emergency department: a randomized clinical trial. *International Journal of Medical Informatics.* 2014;83(11):805-813. doi: 10.1016/j.ijmedinf.2014.07.008.	Intervention did not aim to improve communication
12	Ebrahimabadi M, Rezaei K, Moini A, Fournier A, Abedi A. Infographics or video; which one is more effective in asthmatic patients' health? a randomized clinical trial. *Journal of Asthma.* 2019;56(12):1306-1313. doi: 10.1080/02770903.2018.1536143.	Participants aged over 18 years, or data for participants under 18 could not be extracted

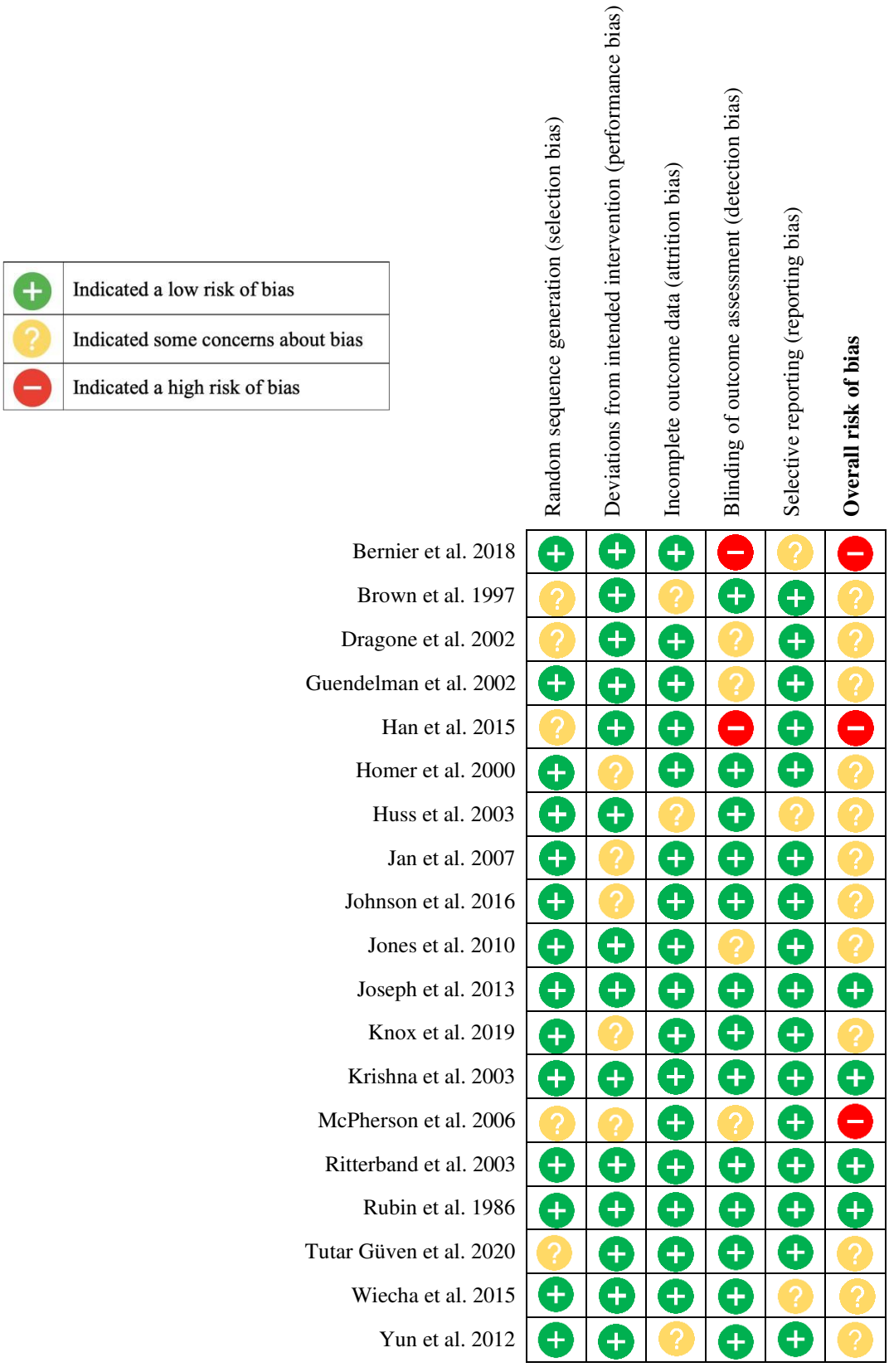
		(participants aged over 18 years)
13	Faraji S, Valizadeh S, Sharifi A, Shahbazi S, Ghojazadeh M. The effectiveness of telegram-based virtual education versus in-person education on the quality of life in adolescents with moderate-to-severe asthma: a pilot randomized controlled trial. *Nursing Open.* 2020;7(6):1691-1697. doi: 10.1002/nop2.552.	Participants aged over 18 years, or data for participants under 18 could not be extracted *(participants aged 12-19 years)*
14	Farmer A, Gibson O, Hayton P, Bryden K, Dudley C, Neil A et al.. A real-time, mobile phone-based telemedicine system to support young adults with type 1 diabetes. *Informatics in Primary Care.* 2005;13(3):171-177. doi: 10.14236/jhi.v13i3.594.	Study not randomised controlled trial
15	Franklin VL, Waller A, Pagliari C, Greene SA. A randomized controlled trial of Sweet Talk, a text-messaging system to support young people with diabetes. *Diabetic Medicine.* 2006;23(12):1332-1338. doi: 10.1111/j.1464-5491.2006.01989.x.	Intervention not interacted with or only partially interacted with by the child
16	Gay CL, Chapuis F, Bendelac N, Tixier F, Treppoz S, Nicolino M. Reinforced follow-up for children and adolescents with type 1 diabetes and inadequate glycaemic control: a randomized controlled trial intervention via the local pharmacist and telecare. *Diabetes and Metabolism.* 2006;32(2):159-165. doi: 10.1016/s1262-3636(07)70263-x.	Intervention acted only as facilitator for the logistics of communication
17	Gilljam BM, Nygren JM, Svedberg P, Arvidsson S. Impact of an electronic health service on child participation in pediatric oncology care: quasi-experimental study. *Journal of Medical Internet Research.* 2020;22(7):e17673. doi: 10.2196/17673.	Study not randomised controlled trial
18	Greenley RN, Gumidyala AP, Nguyen E, Plevinsky JM, Poulopoulos N, Thomason MM et al.. Can you teach a teen new tricks? Problem solving skills training improves oral medication adherence in pediatric patients with inflammatory bowel disease participating in a randomized trial. *Inflammatory Bowel Disease.* 2015;21(11):2649-2657. doi: 10.1097/MIB.0000000000000530.	Intervention acted only as facilitator for the logistics of communication
19	Gregory JW, Robling M, Bennert K, Channon S, Cohen D, Crowne E et al. Development and evaluation by a cluster randomised trial of a psychosocial intervention in children and teenagers experiencing diabetes: The DEPICTED study. *Health Technology Assessment.* 2011;15(29):1-202. doi: 10.3310/hta15290.	Intervention not technological *(web-based aspect of intervention not distinguishable for analysis)*
20	Gur M, Nir V, Teleshov A, Bar-Yoseph R, Manor E, Diab G et al.. The use of telehealth (text messaging and video communications) in patients with cystic fibrosis: A pilot study. *Journal of Telemedicine and Telecare.* 2017;23(4):489-493. doi: 10.1177/1357633X16649532.	Study not randomised controlled trial
21	Gustafson D, Wise M, Bhattacharya A, Pulvermacher A, Shanovich K, Phillips B et al. The effects of combining Web-based eHealth with telephone nurse case management for pediatric asthma control: a randomized controlled trial. *Journal of Medical Internet Research.* 2012;14(4):e101. doi: 10.2196/jmir.1964.	Intervention not interacted with or only partially interacted with by the child *(interacted with by parents)*
22	Hanberger L, Ludvigsson J, Nordfeldt S. Use of a web 2.0 portal to improve education and communication in young patients with families: Randomized controlled trial. *Journal of Medical Internet Research.* 2013;15(8):e175. doi: 10.2196/jmir.2425.	Intervention not interacted with or only partially interacted with by the child *(interacted with by parents)*
23	Haverman L, van Rossum MA, van Veenendaal M, van der Berg JM, Dolman KM, Swart J et al. Effectiveness of a web-based application to monitor health-related quality of life. *Pediatrics.* 2013;131(2):e533-543. doi: 10.1542/peds.2012-0958.	Intervention not interacted with or only partially interacted with by the child
24	Iafusco D, Galderisi A, Nocerino I, Cocca A, Zuccotti G, Prisco F et al. Chat line for adolescents with type 1 diabetes: a useful tool to improve coping with diabetes: a 2-year follow-up study. *Diabetes Technology & Therapeutics.* 2011;13(5):551-555. doi: 10.1089/dia.2010.0188.	Study not randomised controlled trial
25	Jha KK, Karunanithi GB, Sahana A, Karthikbabu S. Randomised trial of virtual reality gaming and physiotherapy on balance, gross motor performance and daily functions among children with bilateral spastic cerebral palsy. *Somatosensory & Motor Research.* 2021;38(2):117-126. doi: 10.1080/08990220.2021.1876016.	Intervention did not aim to improve communication *(acts as physical therapy)*
26	Khan R, Yasin F, O'Neill S, Cahalane E, O'Shea R, Browne B et al. DVD versus physiotherapist-led inhaler education: A randomised controlled trial. *Irish Medical Journal.* 2018;111(2):694. PMID: 29952443.	Intervention not interacted with or only partially interacted with by the child

27	Kunin-Batson A, Steele J, Mertens A, Neglia JP. A randomized controlled pilot trial of a Web-based resource to improve cancer knowledge in adolescent and young adult survivors of childhood cancer. *Psychooncology.* 2016;25(11):1308-1316. doi: 10.1002/pon.3956.	Participants aged over 18 years, or data for participants under 18 could not be extracted *(participants aged 15-29 years)*
28	Looman WS, Antolick M, Cady RG, Lunos SA, Garwick AE, Finkelstein SM. Effects of a telehealth care coordination intervention on perceptions of health care by caregivers of children with medical complexity: a randomized controlled trial. *Journal of Pediatric Health Care.* 2015;29(4):352-363. doi: 10.1016/j.pedhc.2015.01.007.	Intervention not interacted with or only partially interacted with by the child *(interacted with by parents)*
29	Lua PL, Neni WS. Health-related quality of life improvement via telemedicine for epilepsy: printed versus SMS-based education intervention. *Quality of Life Research.* 2013;22(8):2123-2132. doi: 10.1007/s11136-013-0352-6.	Participants aged over 18 years, or data for participants under 18 could not be extracted *(participants aged over 18 years)*
30	Lv S, Ye X, Wang Z, Xia W, Qi Y, Wang W et al. A randomized controlled trial of a mobile application-assisted nurse-led model used to improve treatment outcomes in children with asthma. *Journal of Advanced Nursing.* 2019;75(11):3058-3067. doi: 10.1111/jan.14143.	Intervention not interacted with or only partially interacted with by the child *(interacted with by parents)*
31	Maher CA, Williams MT, Olds T, Lane AE. An internet-based physical activity intervention for adolescents with cerebral palsy: a randomized controlled trial. *Developmental Medicine & Child Neurology.* 2010;52(5):448.455. doi: 10.1111/j.1469-8749.2009.03609.x.	Intervention did not aim to improve communication
32	Marciel KK, Saiman L, Quittell LM, Dawkins K, Quittner AL. Cell phone intervention to improve adherence: Cystic fibrosis care team, patient, and parent perspectives. *Pediatric Pulmonology.* 2010;45(2):157-164. doi: 10.1002/ppul.21164.	Study not randomised controlled trial
33	McGhan SL, Wong E, Jhangri GS, Wells HM, Michaelchuk DR, Boechler VL et al. Evaluation of an education program for elementary school children with asthma. *Journal of Asthma.* 2003;40(5):523-533. doi: 10.1081/jas-120018785.	Intervention not technological
34	McGhan SL, Wong E, Sharpe HM, Hessel PA, Mandhane P, Boechler VL et al. A children's asthma education program: Roaring Adventures of Puff (RAP), improves quality of life. *Canadian Respiratory Journal.* 2010;17(2):67-73. doi: 10.1155/2010/327650.	Intervention not technological
35	Mulvaney SA, Anders S, Smith AK, Pittel EJ, Johnson KB. A pilot test of a tailored mobile and web-based diabetes messaging system for adolescents. *Journal of Telemedicine and Telecare.* 2012;18(2):115-118. doi: 10.1258/jtt.2011.111006.	Study not randomised controlled trial
36	Nemanic T, Sarc I, Skrgat S, Flezar M, Cukjati I, Malovrh MM. Telemonitoring in asthma control: a randomized controlled trial. *Journal of Asthma.* 2019;56(7):782-790. doi: 10.1080/02770903.2018.1493599.	Participants aged over 18 years, or data for participants under 18 could not be extracted *(participants aged over 18 years)*
37	Ng JS, Chau JP, Chan AW, Lui JK, Cheng JW. A nurse-led web-based home asthma education programme for children and their families: a randomized controlled trial. *Journal of Pediatric Nursing.* 2021;59:158-163. doi: 10.1016/j.pedn.2021.04.014.	Intervention not interacted with or only partially interacted with by the child *(interacted with by parents)*
38	Phillips JH, Wigger C, Beissbarth J, McCallum GB, Leach A, Morris PS. Can mobile phone multimedia messages and text messages improve clinic attendance for Aboriginal children with chronic otitis media? A randomised controlled trial. *Journal of Paediatrics and Child Health.* 2014;50(5):362-367. doi: 10.1111/jpc.12496.	Intervention not interacted with or only partially interacted with by the child
39	Reid SC, Kauer SD, Hearps SJ, Crooke AH, Khor A, Sanci LA et al. A mobile phone application for the assessment and management of youth mental health problems in primary care: a randomised controlled trial. *BMC Family Practice.* 2011;12(1):131. doi: 10.1186/1471-2296-12-131.	Participants aged over 18 years, or data for participants under 18 could not be extracted *(participants aged 14-24 years)*
40	Savage I, Goodyer L. Providing information on metered dose inhaler technique: Is multimedia as effective as print? *Family Practice.* 2003;20(5):552-557. doi: 10.1093/fampra/cmg510.	Participants aged over 18 years, or data for participants under 18 could not be extracted *(participants aged 12-87 years)*

41	Schmidt A, Greuter T, Möller A, Steib JO. Effectiveness and practicality of an internet-based asthma refresher course for children and adolescents. *Pneumologie.* 2014;68(4):259-265. doi: 10.1055/s-0033-1358921.	Study not randomised controlled trial
42	Schwartz LA, Daniel LC, Henry-Moss D, Bonafide CP, Li Y, Psihogios AM et al. Feasibility and acceptability of a pilot tailored text messaging intervention for adolescents and young adults completing cancer treatment. *Psychooncology.* 2020;29(1):164-172. doi: 10.1002/pon.5287.	Participants aged over 18 years, or data for participants under 18 could not be extracted *(participants aged 12-25 years)*
43	Shegog R, Bartholomew LK, Parcel GS, Sockrider MM, Mâsse L, Abramson SL. Impact of a computer-assisted education program on factors related to asthma self-management behaviour. *Journal of the American Medical Informatics Association.* 2001;8(1):49-61. doi: 10.1136/jamia.2001.0080049.	Study not randomised controlled trial
44	Stinson J, Ahola Kohut S, Forgeron P, Amaria K, Bell M, Kaufman M et al. The iPeer2Peer Program: a pilot randomized controlled trial in adolescents with juvenile idiopathic arthritis. *Pediatric Rheumatology.* 2016;14(1):48. doi: 10.1186/s12969-016-0108-2.	Intervention acted only as facilitator for the logistics of communication
45	Tung J, Grunow JE, Jacobs N. Pilot development of an electronic pediatric inflammatory bowel disease quiz game. *Journal of Pediatric Gastroenterology and Nutrition.* 2015;61(3):292-296. doi: 10.1097/MPG.0000000000000788.	Study not randomised controlled trial
46	Vasbinder EC, Goossens LM, Rutten-van Mölken MP, de Winter BC, van Dijk L, Vulto AG et al. e-Monitoring of Asthma Therapy to Improve Compliance in children (e-MATIC): a randomised controlled trial. *European Respiratory Journal.* 2016;48(3):758-767. doi: 10.1183/13993003.01698-2015.	Intervention not interacted with or only partially interacted with by the child
47	Whittemore R, Jaser SS, Jeon S, Liberti L, Delamater A, Murphy K et al. An internet coping skills training program for youth with type 1 diabetes: six-month outcomes. *Nursing Research.* doi: 10.1097/NNR.0b013e3182690a29.	Intervention did not aim to improve communication
48	Williamson H, Hamlet C, White P, Marques EM, Paling T, Cadogan J et al. A web-based self-help psychosocial intervention for adolescents distressed by appearance-affecting conditions and injuries (Young Persons' Face IT): feasibility study for a parallel randomized controlled trial. *JMIR Mental Health.* 2019;6(11):e14776. doi: 10.2196/14776.	Intervention did not aim to improve communication *(therapy)*
49	Wolfe J, Orellana L, Francis Cook E, Ullrich C, Kang T, Russell Geyer J et al. Improving the care of children with advanced cancer by using an electronic patient-reported feedback intervention: Results from the PediQUEST randomized controlled trial. *Journal of Clinical Oncology.* 2014;32(11):1119-1126. doi: 10.1200/JCO.2013.51.5981.	Intervention did not aim to improve communication
50	Xu C, Jackson M, Scuffham PA, Wootton R, Simpson P, Whitty J et al. A randomized controlled trial of an interactive voice response telephone system and specialist nurse support for childhood asthma management. *Journal of Asthma.* 2010;47(7):768-773. doi: 10.3109/02770903.2010.493966.	Intervention not interacted with or only partially interacted with by the child *(interacted with by parents)*
51	Yawn BP, Algatt-Bergstrom PJ, Yawn RA, Wollan P, Greco M, Gleason M et al. An in-school CD-ROM asthma education program. 2000;70(4):153-159. doi: 10.1111/j.1746-1561.2000.tb06462.x.	Not all participants had a long-term condition

Supplementary File 5

Risk of Bias decision for included studies



Supplementary File 6

GRADE strength of evidence profile

	Number of participants		Quality assessment					
Number of studies	Intervention	Control	Risk of bias	Publication bias	Imprecision	Inconsistency	Indirectness	Quality
KNOWLEDGE								
11	319	279	Serious limitations 2 high risk of bias 6 some concerns 3 low risk of bias	Undetected	No serious imprecision 95% CI: 0.07, 0.71	Serious limitations I^2 = 70% Heterogeneity p = 0.0002	No serious indirectness Adhered to review eligibility criteria	**LOW** strength of evidence
HEALTH LOCUS OF CONTROL								
4	129	122	Serious limitations 1 high risk of bias 2 some concerns 1 low risk of bias	Undetected	No serious imprecision 95% CI: 0.25, 0.76	No serious limitations I^2 = 0% Heterogeneity p = 0.71	No serious indirectness Adhered to review eligibility criteria	**MODERATE** strength of evidence
EMERGENCY HEALTHCARE USE								
4	170	157	No serious limitations 2 some concerns 2 low risk of bias	Undetected	Serious imprecision 95% CI: -0.42, 0.02 Urgent physician and emergency visits collated	No serious limitations I^2 = 0% Heterogeneity p = 0.52	No serious indirectness Adhered to review eligibility criteria	**MODERATE** strength of evidence
PHYSIOLOGICAL MEASURES								
6	212	184	Very serious limitations 2 high risk of bias 4 some concerns	Undetected	Serious imprecision Asthma 95% CI: -0.19, 0.51 Diabetes 95% CI: -0.18, 0.35	No serious limitations I^2 = 0% Heterogeneity p = 0.74	No serious indirectness Adhered to review eligibility criteria	**VERY LOW** strength of evidence

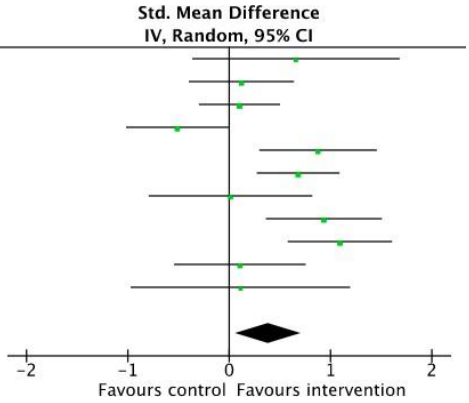
Supplementary File 7

Meta-analysis results presented using forest plots

7.1.1 : Forest plot for knowledge outcome

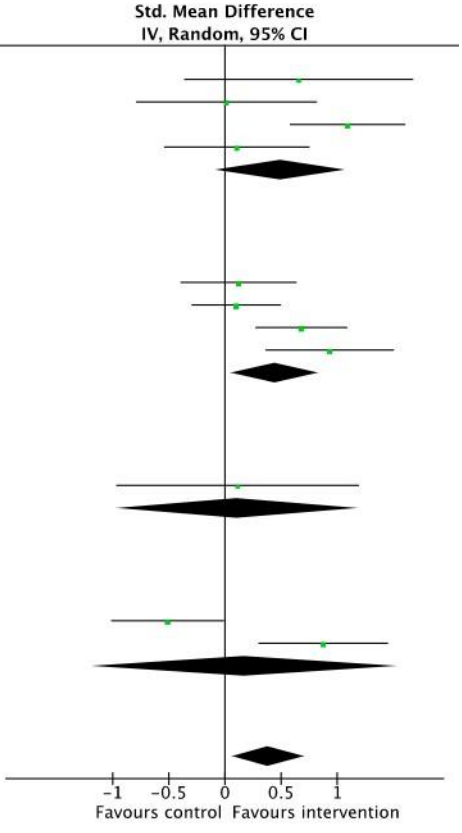
Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bernier et al. 2018	3.88	3.379	8	1.88	2.262	8	5.8%	0.66 [-0.36, 1.67]
Brown et al. 1997	1.16	3.23	31	0.68	4.54	28	10.2%	0.12 [-0.39, 0.63]
Huss et al. 2003	0.5	1.788	56	0.3	2.174	45	11.4%	0.10 [-0.29, 0.49]
Jones et al. 2010	-0.06	3.106	35	1.55	3.106	30	10.3%	-0.51 [-1.01, -0.02]
Krishna et al. 2003	10	6.99	25	4.44	5.49	27	9.6%	0.88 [0.30, 1.45]
McPherson et al. 2006	3.97	3.604	50	1.55	3.45	51	11.3%	0.68 [0.28, 1.08]
Ritterband et al. 2003	3.83	2.943	12	3.78	4.202	12	7.4%	0.01 [-0.79, 0.81]
Rubin et al. 1986	14.4	13.4	29	2	12.7	25	9.6%	0.93 [0.37, 1.50]
Tutar Güven et al. 2020	0.36	0.343	35	-0.01	0.326	34	10.2%	1.09 [0.58, 1.60]
Wiecha et al. 2015	5	61.537	28	-1	41.155	14	8.8%	0.11 [-0.54, 0.75]
Yun et al. 2012	1	1.7348	10	0.8	1.518	5	5.4%	0.11 [-0.96, 1.19]
Total (95% CI)			**319**			**279**	**100.0%**	**0.39 [0.07, 0.71]**

Heterogeneity: $Tau^2 = 0.19$; $Chi^2 = 33.68$, df = 10 (P = 0.0002); $I^2 = 70\%$
Test for overall effect: Z = 2.38 (P = 0.02)



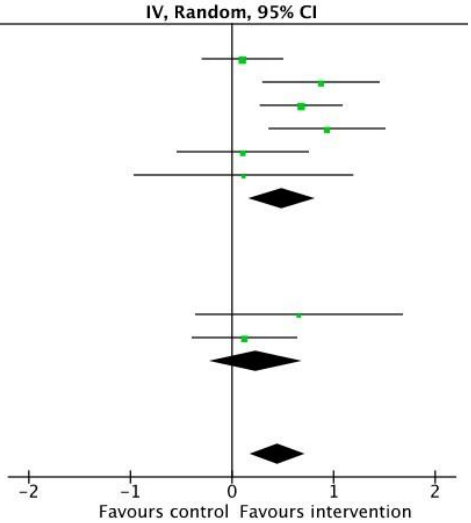
7.1.2 : Forest plot for knowledge outcome (technology subgroups)

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.6.1 Website								
Bernier et al. 2018	3.88	3.379	8	1.88	2.262	8	5.8%	0.66 [-0.36, 1.67]
Ritterband et al. 2003	3.83	2.943	12	3.78	4.202	12	7.4%	0.01 [-0.79, 0.81]
Tutar Güven et al. 2020	0.36	0.343	35	-0.01	0.326	34	10.2%	1.09 [0.58, 1.60]
Wiecha et al. 2015	5	61.537	28	-1	41.155	14	8.8%	0.11 [-0.54, 0.75]
Subtotal (95% CI)			**83**			**68**	**32.2%**	**0.49 [-0.09, 1.07]**
Heterogeneity: $Tau^2 = 0.21$; $Chi^2 = 7.96$, df = 3 (P = 0.05); $I^2 = 62\%$								
Test for overall effect: Z = 1.67 (P = 0.09)								
1.6.2 Video game								
Brown et al. 1997	1.16	3.23	31	0.68	4.54	28	10.2%	0.12 [-0.39, 0.63]
Huss et al. 2003	0.5	1.788	56	0.3	2.174	45	11.4%	0.10 [-0.29, 0.49]
McPherson et al. 2006	3.97	3.604	50	1.55	3.45	51	11.3%	0.68 [0.28, 1.08]
Rubin et al. 1986	14.4	13.4	29	2	12.7	25	9.6%	0.93 [0.37, 1.50]
Subtotal (95% CI)			**166**			**149**	**42.5%**	**0.44 [0.05, 0.83]**
Heterogeneity: $Tau^2 = 0.10$; $Chi^2 = 8.65$, df = 3 (P = 0.03); $I^2 = 65\%$								
Test for overall effect: Z = 2.22 (P = 0.03)								
1.6.3 Texting								
Yun et al. 2012	1	1.7348	10	0.8	1.518	5	5.4%	0.11 [-0.96, 1.19]
Subtotal (95% CI)			**10**			**5**	**5.4%**	**0.11 [-0.96, 1.19]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.21 (P = 0.84)								
1.6.4 CD-ROM								
Jones et al. 2010	-0.06	3.106	35	1.55	3.106	30	10.3%	-0.51 [-1.01, -0.02]
Krishna et al. 2003	10	6.99	25	4.44	5.49	27	9.6%	0.88 [0.30, 1.45]
Subtotal (95% CI)			**60**			**57**	**19.9%**	**0.17 [-1.19, 1.53]**
Heterogeneity: $Tau^2 = 0.89$; $Chi^2 = 12.92$, df = 1 (P = 0.0003); $I^2 = 92\%$								
Test for overall effect: Z = 0.25 (P = 0.80)								
Total (95% CI)			**319**			**279**	**100.0%**	**0.39 [0.07, 0.71]**
Heterogeneity: $Tau^2 = 0.19$; $Chi^2 = 33.68$, df = 10 (P = 0.0002); $I^2 = 70\%$								
Test for overall effect: Z = 2.38 (P = 0.02)								
Test for subgroup differences: $Chi^2 = 0.52$, df = 3 (P = 0.92), $I^2 = 0\%$								



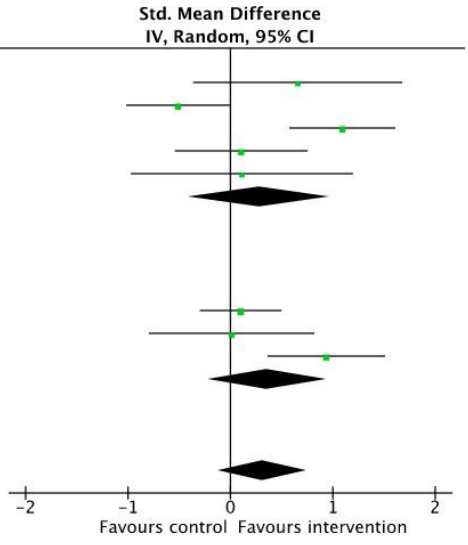
7.1.3 : Forest plot for knowledge outcome (condition subgroups)

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.5.1 Asthma								
Huss et al. 2003	0.5	1.788	56	0.3	2.174	45	18.6%	0.10 [-0.29, 0.49]
Krishna et al. 2003	10	6.99	25	4.44	5.49	27	13.0%	0.88 [0.30, 1.45]
McPherson et al. 2006	3.97	3.604	50	1.55	3.45	51	18.3%	0.68 [0.28, 1.08]
Rubin et al. 1986	14.4	13.4	29	2	12.7	25	13.1%	0.93 [0.37, 1.50]
Wiecha et al. 2015	5	61.537	28	-1	41.155	14	11.3%	0.11 [-0.54, 0.75]
Yun et al. 2012	1	1.7348	10	0.8	1.518	5	5.3%	0.11 [-0.96, 1.19]
Subtotal (95% CI)			**198**			**167**	**79.5%**	**0.50 [0.17, 0.83]**
Heterogeneity: $Tau^2 = 0.08$; $Chi^2 = 10.61$, df = 5 (P = 0.06); $I^2 = 53\%$								
Test for overall effect: Z = 2.98 (P = 0.003)								
1.5.2 Diabetes								
Bernier et al. 2018	3.88	3.379	8	1.88	2.262	8	5.8%	0.66 [-0.36, 1.67]
Brown et al. 1997	1.16	3.23	31	0.68	4.54	28	14.6%	0.12 [-0.39, 0.63]
Subtotal (95% CI)			**39**			**36**	**20.5%**	**0.23 [-0.23, 0.69]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.86$, df = 1 (P = 0.35); $I^2 = 0\%$								
Test for overall effect: Z = 0.99 (P = 0.32)								
Total (95% CI)			**237**			**203**	**100.0%**	**0.45 [0.18, 0.73]**
Heterogeneity: $Tau^2 = 0.06$; $Chi^2 = 12.48$, df = 7 (P = 0.09); $I^2 = 44\%$								
Test for overall effect: Z = 3.26 (P = 0.001)								
Test for subgroup differences: $Chi^2 = 0.88$, df = 1 (P = 0.35), $I^2 = 0\%$								



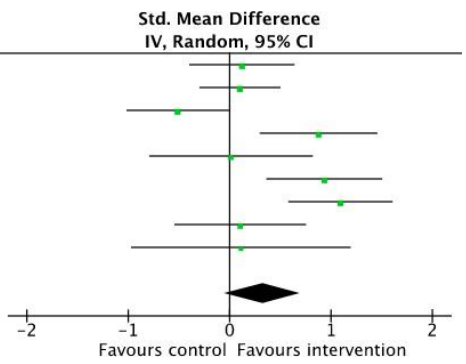
7.1.4 : Forest plot for knowledge outcome (age subgroups)

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.7.1 Adolescents								
Bernier et al. 2018	3.88	3.379	8	1.88	2.262	8	9.0%	0.66 [-0.36, 1.67]
Jones et al. 2010	-0.06	3.106	35	1.55	3.106	30	14.6%	-0.51 [-1.01, -0.02]
Tutar Güven et al. 2020	0.36	0.343	35	-0.01	0.326	34	14.4%	1.09 [0.58, 1.60]
Wiecha et al. 2015	5	61.537	28	-1	41.155	14	12.9%	0.11 [-0.54, 0.75]
Yun et al. 2012	1	1.7348	10	0.8	1.518	5	8.5%	0.11 [-0.96, 1.19]
Subtotal (95% CI)			**116**			**91**	**59.4%**	**0.28 [-0.41, 0.98]**
Heterogeneity: $Tau^2 = 0.48$; $Chi^2 = 20.52$, df = 4 (P = 0.0004); $I^2 = 81\%$								
Test for overall effect: Z = 0.80 (P = 0.42)								
1.7.2 Under 10s								
Huss et al. 2003	0.5	1.788	56	0.3	2.174	45	15.7%	0.10 [-0.29, 0.49]
Ritterband et al. 2003	3.83	2.943	12	3.78	4.202	12	11.1%	0.01 [-0.79, 0.81]
Rubin et al. 1986	14.4	13.4	29	2	12.7	25	13.8%	0.93 [0.37, 1.50]
Subtotal (95% CI)			**97**			**82**	**40.6%**	**0.36 [-0.22, 0.94]**
Heterogeneity: $Tau^2 = 0.18$; $Chi^2 = 6.30$, df = 2 (P = 0.04); $I^2 = 68\%$								
Test for overall effect: Z = 1.21 (P = 0.22)								
Total (95% CI)			**213**			**173**	**100.0%**	**0.31 [-0.12, 0.74]**
Heterogeneity: $Tau^2 = 0.27$; $Chi^2 = 26.91$, df = 7 (P = 0.0003); $I^2 = 74\%$								
Test for overall effect: Z = 1.42 (P = 0.16)								
Test for subgroup differences: $Chi^2 = 0.03$, df = 1 (P = 0.87), $I^2 = 0\%$								



7.1.5 : Forest plot for knowledge outcome (sensitivity analysis excluding high risk of bias studies)

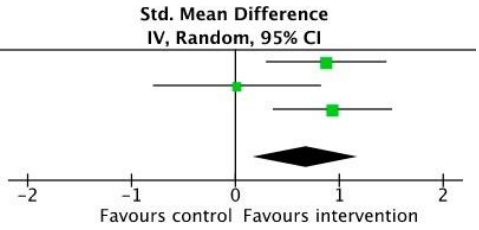
Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Brown et al. 1997	1.16	3.23	31	0.68	4.54	28	12.2%	0.12 [-0.39, 0.63]
Huss et al. 2003	0.5	1.788	56	0.3	2.174	45	13.4%	0.10 [-0.29, 0.49]
Jones et al. 2010	-0.06	3.106	35	1.55	3.106	30	12.3%	-0.51 [-1.01, -0.02]
Krishna et al. 2003	10	6.99	25	4.44	5.49	27	11.5%	0.88 [0.30, 1.45]
Ritterband et al. 2003	3.83	2.943	12	3.78	4.202	12	9.2%	0.01 [-0.79, 0.81]
Rubin et al. 1986	14.4	13.4	29	2	12.7	25	11.6%	0.93 [0.37, 1.50]
Tutar Güven et al. 2020	0.36	0.343	35	-0.01	0.326	34	12.2%	1.09 [0.58, 1.60]
Wiecha et al. 2015	5	61.537	28	-1	41.155	14	10.8%	0.11 [-0.54, 0.75]
Yun et al. 2012	1	1.7348	10	0.8	1.518	5	6.9%	0.11 [-0.96, 1.19]
Total (95% CI)			**261**			**220**	**100.0%**	**0.33 [-0.05, 0.70]**
Heterogeneity: $Tau^2 = 0.23$; $Chi^2 = 30.78$, df = 8 (P = 0.0002); $I^2 = 74\%$								
Test for overall effect: Z = 1.71 (P = 0.09)								



7.1.6 : Forest plot for knowledge outcome (sensitivity analysis including only low risk of bias studies)

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Krishna et al. 2003	10	6.99	25	4.44	5.49	27	37.0%	0.88 [0.30, 1.45]
Ritterband et al. 2003	3.83	2.943	12	3.78	4.202	12	25.5%	0.01 [-0.79, 0.81]
Rubin et al. 1986	14.4	13.4	29	2	12.7	25	37.4%	0.93 [0.37, 1.50]
Total (95% CI)			**66**			**64**	**100.0%**	**0.68 [0.17, 1.18]**

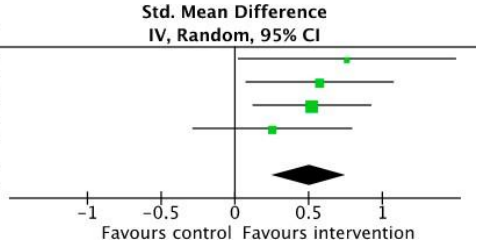
Heterogeneity: $Tau^2 = 0.10$; $Chi^2 = 3.83$, df = 2 (P = 0.15); $I^2 = 48\%$
Test for overall effect: Z = 2.62 (P = 0.009)



7.2.1 : Forest plot for health locus of control outcome

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dragone et al. 2002	1.524	2.8346	15	-0.81	3.1294	16	11.9%	0.76 [0.03, 1.49]
Jones et al. 2010	3.86	4.716	35	0.97	5.243	30	25.7%	0.58 [0.08, 1.07]
McPherson et al. 2006	0.82	2.101	50	-0.19	1.73	51	40.4%	0.52 [0.12, 0.92]
Rubin et al. 1986	1.3	6.1	29	-0.9	10.7	25	22.1%	0.25 [-0.28, 0.79]
Total (95% CI)			**129**			**122**	**100.0%**	**0.50 [0.25, 0.76]**

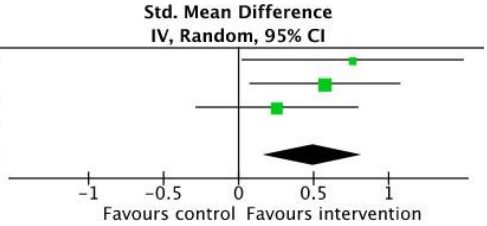
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.39$, df = 3 (P = 0.71); $I^2 = 0\%$
Test for overall effect: Z = 3.92 (P < 0.0001)



7.2.2 : Forest plot for health locus of control outcome (sensitivity analysis excluding high risk of bias studies)

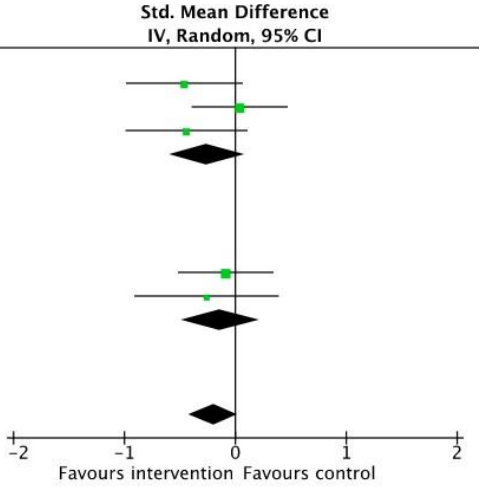
Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dragone et al. 2002	1.524	2.8346	15	-0.81	3.1294	16	19.9%	0.76 [0.03, 1.49]
Jones et al. 2010	3.86	4.716	35	0.97	5.243	30	43.1%	0.58 [0.08, 1.07]
Rubin et al. 1986	1.3	6.1	29	-0.9	10.7	25	37.0%	0.25 [-0.28, 0.79]
Total (95% CI)			**79**			**71**	**100.0%**	**0.49 [0.17, 0.82]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.37$, df = 2 (P = 0.50); $I^2 = 0\%$
Test for overall effect: Z = 2.96 (P = 0.003)

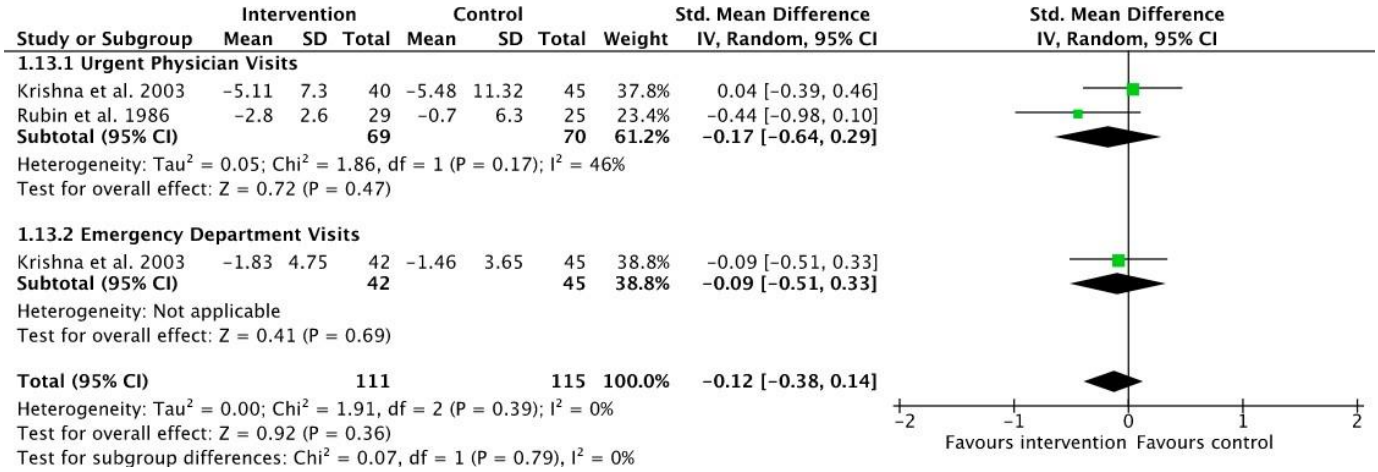


7.3.1 : Forest plot for emergency healthcare use outcome

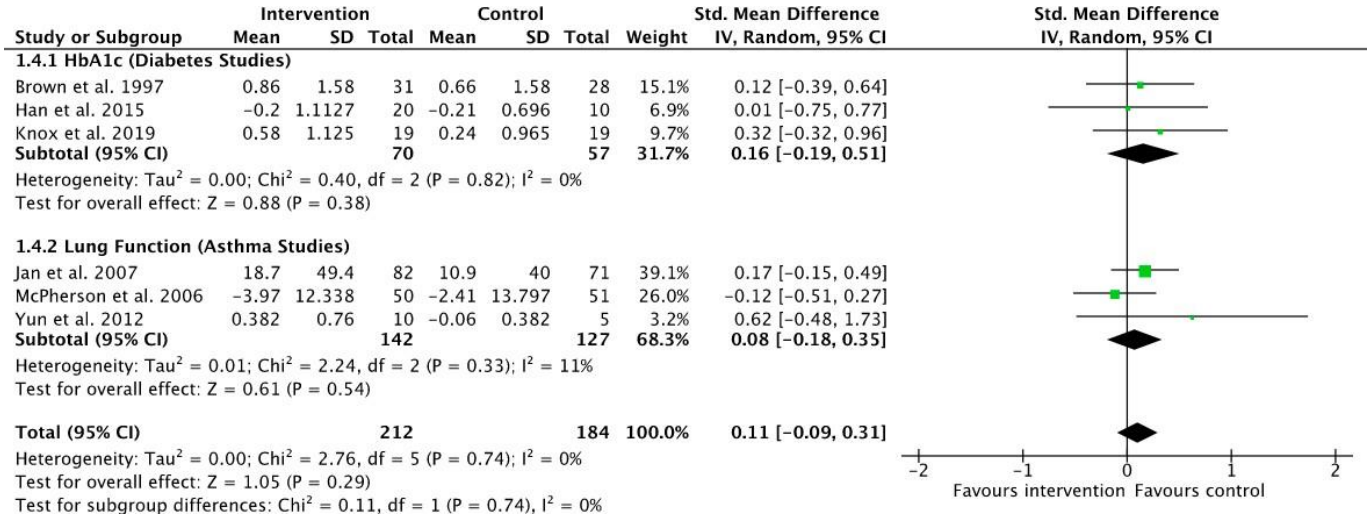
Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.3.1 Urgent Physician Visits								
Brown et al. 1997	-0.43	0.9	31	0.04	1.11	28	18.0%	-0.46 [-0.98, 0.06]
Krishna et al. 2003	-5.11	7.3	40	-5.48	11.32	45	26.6%	0.04 [-0.39, 0.46]
Rubin et al. 1986	-2.8	2.6	29	-0.7	6.3	25	16.5%	-0.44 [-0.98, 0.10]
Subtotal (95% CI)			**100**			**98**	**61.1%**	**-0.25 [-0.59, 0.09]**
Heterogeneity: $Tau^2 = 0.03$; $Chi^2 = 2.87$, df = 2 (P = 0.24); $I^2 = 30\%$								
Test for overall effect: Z = 1.47 (P = 0.14)								
1.3.2 Emergency Department Visits								
Krishna et al. 2003	-1.83	4.75	42	-1.46	3.65	45	27.3%	-0.09 [-0.51, 0.33]
Wiecha et al. 2015	-4	17.705	28	0	7.31	14	11.6%	-0.26 [-0.90, 0.38]
Subtotal (95% CI)			**70**			**59**	**38.9%**	**-0.14 [-0.49, 0.21]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.19$, df = 1 (P = 0.66); $I^2 = 0\%$								
Test for overall effect: Z = 0.77 (P = 0.44)								
Total (95% CI)			**170**			**157**	**100.0%**	**-0.20 [-0.42, 0.02]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 3.25$, df = 4 (P = 0.52); $I^2 = 0\%$								
Test for overall effect: Z = 1.78 (P = 0.08)								
Test for subgroup differences: $Chi^2 = 0.22$, df = 1 (P = 0.64), $I^2 = 0\%$								



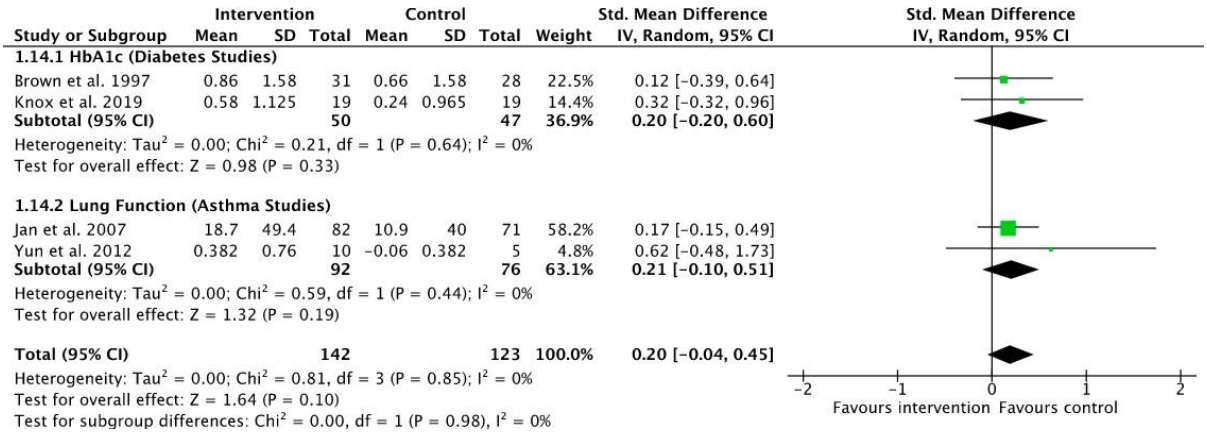
7.3.2 : Forest plot for emergency healthcare use outcome (sensitivity analysis including only low risk of bias studies)



7.4.1 : Forest plot for physiological measures outcome



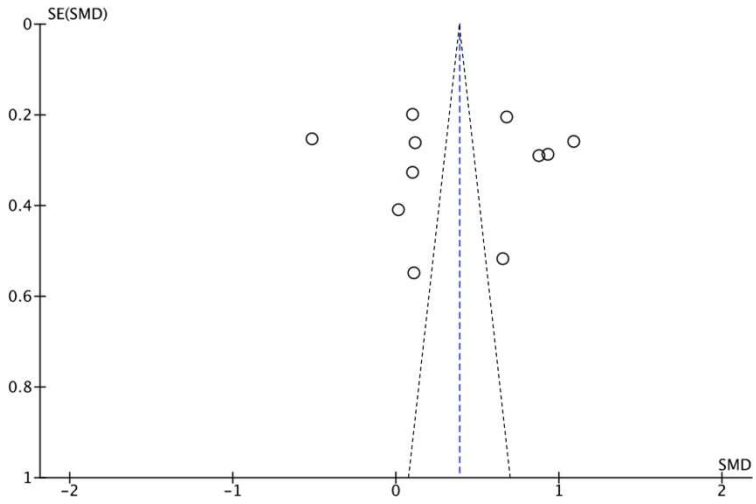
7.4.2 : Forest plot for physiological measures outcome (sensitivity analysis excluding high risk of bias studies)



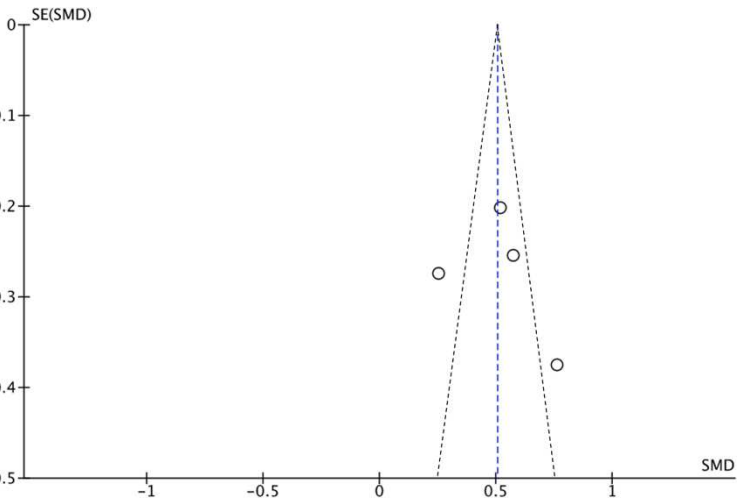
Supplementary File 8

Reporting bias assessment

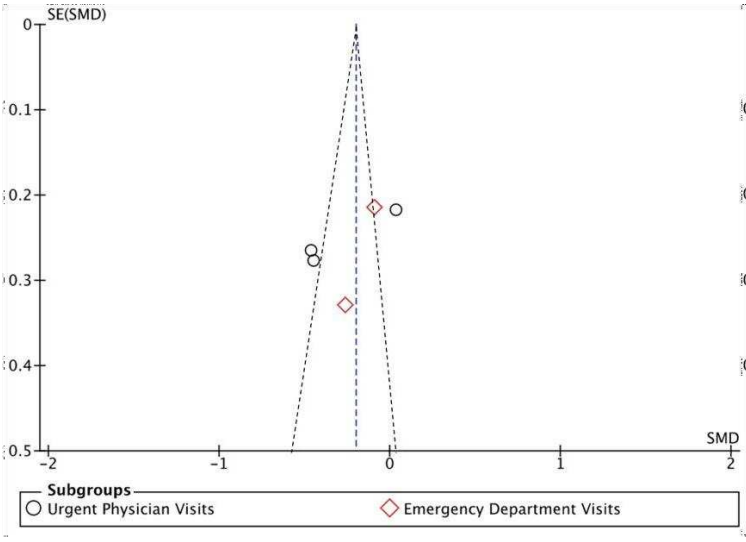
8.1: Funnel plot for knowledge outcome



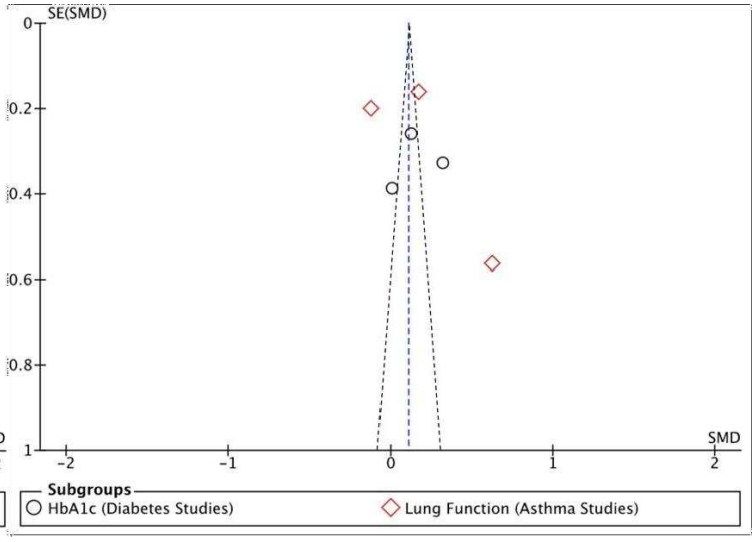
8.2: Funnel plot for health locus of control outcome



8.3: Funnel plot for emergency healthcare use outcome



8.4: Funnel plot for physiological measures outcome



Author Contributions

Effectiveness of technological interventions to improve healthcare communication with children with long-term conditions: a systematic review and meta-analysis of randomised controlled trials

Authors: Emma Dorgeat, Ayowade Adeleye, Dr Kate J Lifford, Professor Adrian Edwards

CRediT author statement:

Emma Dorgeat: Methodology, Investigation, Formal Analysis, Writing - Original Draft, Visualisation. **Ayowade Adeleye:** Validation, Writing - Review & Editing. **Kate Lifford:** Supervision, Conceptualisation, Methodology, Validation, Writing - Review & Editing. **Adrian Edwards:** Supervision, Conceptualisation, Methodology, Validation, Writing - Review & Editing.