Digital interventions to promote self-management in adults with hypertension systematic review and meta-analysis

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**Introduction**

Hypertension is a chronic medical condition in which the blood pressure of the arteries is elevated and is normally defined as being when systolic blood pressure is above 140mmHg and/or diastolic blood pressure is above 90 mmHg.[[1]](#endnote-1) Hypertension has the highest attributable risk for death from cardiovascular disease which is the leading cause of premature morality worldwide.[[2]](#endnote-2) Clinically significant effects and improvements in mortality can be achieved with relatively small reductions in blood pressure levels.[[3]](#endnote-3) [[4]](#endnote-4) However, the rate of control and treatment of hypertension is poor with a large gap found between the detection and control of hypertension.[[5]](#endnote-5) In addition, hypertension is an asymptomatic condition and medications may cause unpleasant side effects exacerbating adherence problems..[[6]](#endnote-6) Consequently, alternative strategies to promote blood pressure control are needed.

Guided self-management for hypertension as part of systematic, planned care offers the potential for improvements in adherence and in turn improved long term patient outcomes. Self-management can encompass a wide range of behaviours in addition to medication titration and monitoring of symptoms, such as an individual’s ability to manage physical, psychosocial and lifestyle behaviours related to their condition.**[[7]](#endnote-7)** Self-management in hypertension including self-titration and behavioural interventions has been shown to be effective.[[8]](#endnote-8) [[9]](#endnote-9)

Despite evidence of benefits, guided self-management and education in the control of hypertension remain underused.[[10]](#endnote-10)Interactive digital interventions (IDIs) can play a crucial role in meeting National Health Service (NHS) policy aims to empower patients to self-manage their long-term conditions, providing patients with better access to personalised information and support for active involvement in treatment as well as producing significant savings in treatment costs. They are web based packages delivered by computer or phone that can combine health information with decision support and help inform behaviour change in patients. IDIs can potentially improve the efficiency of healthcare by automating routine aspects of patient education, monitoring and support, whilst improving services by giving patients convenient 24 hour access to detailed, personalised feedback and allowing health professionals to remotely monitor patient status.[[11]](#endnote-11) [[12]](#endnote-12) There is clear evidence that well-designed IDIs can effectively change patient health-related behaviour, improve patient knowledge and confidence for self-management of health, and lead to better health outcomes.[[13]](#endnote-13) [[14]](#endnote-14) A recent systematic review and meta-analysis on the impact of digital interventions on cardiovascular disease (CVD) outcomes found that IDIs significantly reduced CVD outcomes, weight and body mass index but not blood pressure.[[15]](#endnote-15)

Therefore there is growing interest in the potential of the internet and other digital media as a medium to deliver more tailored, relevant self-management support, while maintaining cost-effectiveness, in support of those with hypertension. There have been a number of reviews which have examined the impact of self-monitoring in adults with hypertension[[16]](#endnote-16) [[17]](#endnote-17) [[18]](#endnote-18) while Liu et al[[19]](#endnote-19) assessed the impact of the internet on blood pressure control assessing both RCTs and case control studies. However, we know of no reviews which focus on RCTs for self management IDIs in those with hypertension and compare with usual care only. Therefore this systematic review aims to synthesise the evidence for using IDIsto support patient self-management of hypertension, and determine their impact on control and reduction of blood pressure, other clinical outcomes, quality of life, medication adherence and economic benefits.

**Methods**

**Design:** systematic review and meta-analysis.

A registered protocol (PROSPERO CRD42013004773) guided the conduct of this review[[20]](#endnote-20), which we reported in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Statement.[[21]](#endnote-21)

**Eligibility criteria**

Inclusion criteria were based on the PICOS acronym[[22]](#endnote-22); (1) the population was adults (18 years and over) with hypertension (as defined by the primary authors);(2) the intervention was an interactive digital intervention (as defined below);(3) the comparator was usual care; (4) outcomes must include objectively measured change in blood pressure (systolic or diastolic); (5) only Randomised Controlled Trials (RCTs) were included as they present the strongest level of evidence; (6) we only considered studies published in journals and in English as evidence suggests that limiting studies in this way does not introduce significant bias.[[23]](#endnote-23)

For the purpose of this review the term IDIs will include any intervention accessed through a computer (work or home), or smartphone or other hand held device and include web based programmes, desktop computer programmes or apps that provide self-management information and can be used on or offline. The intervention must function without the need for directive input from a health professional. They must also be ‘interactive’, which we define as requiring contributions from programme users (e.g. entering personal data, making choices) which alter pathways within programmes to produce tailored material and feedback that is personally relevant to users.

**Information Sources and Search Strategy**

Searches were undertaken by a professional systematic review company the York Health Economic Consortium.[[24]](#endnote-24) The strategies were informed by the intervention search terms used in a previous systematic review conducted by the team on digital asthma self-management interventions.[[25]](#endnote-25) The search strategy combined three concepts and a study type filter for RCTs:

1. Hypertension (lines 1 – 11 of search strategy);
2. Digital interventions (lines 12 - 71);
3. Randomised controlled trials (lines 73 – 80).

The following databases were searched: MEDLINE, EMBASE, CINAHL, PsycINFO, ERIC, Cochrane Library (including CDSR, DARE, Central, NHS EED and HTA databases), DoPHER and TROPHI (both produced by the EPPI Centre), Social Science Citation Index and Science Citation Index. These databases were searched using a combination of subject headings where available (such as MeSH) and words in the title and abstracts.

The search was complemented by contacting experts in the topic under review and by carrying out citation searches for articles which cite individual studies that are included in the review.[[26]](#endnote-26)

**Study selection**

All abstracts identified from the search were downloaded following de-duplication into the Distiller software programme.[[27]](#endnote-27) Abstracts and full papers that met the inclusion criteria were screened by two reviewers working independently. Inter-reviewer disagreements were resolved by seeking consensus between the reviewers or if this was not possible the decision was referred to the steering group. Outcome measures are listed in table 1 with the primary outcomes being changes in mean systolic and diastolic blood pressure and quality of life indicators.

**Table 1 Types of outcome measures**

|  |  |  |
| --- | --- | --- |
| Outcome measure description | Primary Outcome | Secondary Outcome |
| Clinical | Mean systolic and diastolic blood pressure |  |
| Clinical | Quality of life indicators |  |
| **Cognitive** |  | Self-efficacy |
| **Behavioural** |  | Medication adherence |
| **Behavioural** |  | Dietary change |
| **Behavioural** |  | Physical Activity |
| **Affective** |  | Depression |
| Affective |  | Anxiety |
| Affective |  | Emotional wellbeing |
| Affective |  | Satisfaction with care |
| Economic |  | Health service utilisation |
| Economic |  | Costs of intervention |

**Data extraction**

We used online data collection forms using Distiller SR software. Data was extracted on study details (country of origin, inclusion/exclusion criteria, number of participants), participant details (mean age, % male, ethnicity, socio-economic, smoking and comorbidities), intervention details (description, theoretical basis, setting, duration, intensity and format) and outcomes including mean change in systolic blood pressure(SBP) and diastolic blood pressure (DBP), any other clinical outcome changes, behavioural (medication adherence, dietary change, levels of physical change), cognitive (knowledge of condition, satisfaction with care), affective (change in depressive or anxiety levels), and economic (cost effectiveness).

#### Assessment of methodological quality

Risk of bias was assessed in each of the included studies by the two researchers working independently using the Cochrane collaboration tool for assessing bias for guidance.[[28]](#endnote-28) Methods of allocation concealment, randomisation procedure, dropout rate and whether there was evidence of selective outcome reporting were assessed.

**Analysis**

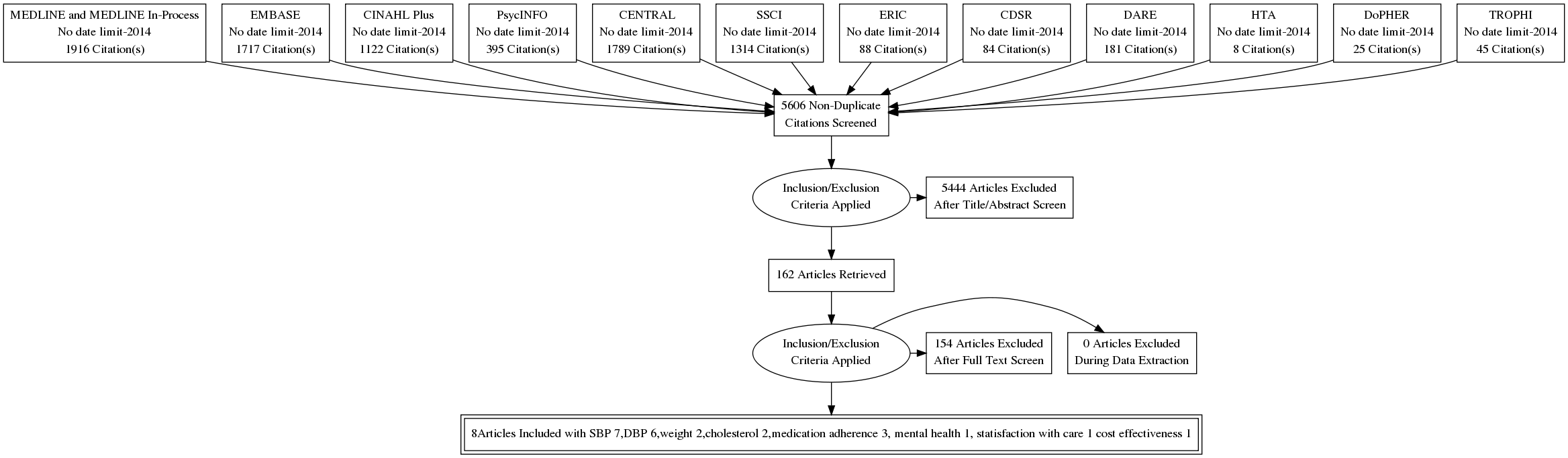
**Analysis of interventions**

Meta-analysis was based on guidelines from the Cochrane Handbook for Systematic Reviews of Interventions.[[29]](#endnote-29)Potential publication bias was assessed by using a funnel plot and Egger’s test. [[30]](#endnote-30) We used a random effects model for the meta-analysis of the difference in mean change in mm Hg for SBP and DBP and kg for weight. A random effect model was used due to the wide variation of the included studies both in terms of the population characteristics (age, gender) but also mean SBP and DBP levels at baseline. Where standard deviation of the change was not reported we estimated the standard deviation using confidence intervals or p-scores. We divided studies into two groups -- those that contained self monitoring of blood pressure and those that did not -- and reported for both groups and overall. Heterogeneity statistics were assessed by the Q statistic and I2 statistics.**[[31]](#endnote-31)**

**Results**

Our search identified 5606 papers, after abstract screening there were 164 papers for full paper review. Eight papers from seven interventions met our criteria and were included (see figure 1).

**Figure 1 Prisma flow chart**



### Description of Included studies

The seven studies included a total of 1,259 participants, with a range of 35 to 387 participants per study (table 1). Three studies had been undertaken in the US[[32]](#endnote-32) [[33]](#endnote-33) [[34]](#endnote-34) [[35]](#endnote-35), and one each in Korea[[36]](#endnote-36), Honduras and Mexico[[37]](#endnote-37), Canada[[38]](#endnote-38), Finland.[[39]](#endnote-39) The studies varied considerably in the nature and delivery of the intervention, the study population, and the outcome measures used.

**Description of Interventions**

A summary of the key components of the interventions are given in table 2.

*Aim of Intervention* -Five of the interventions had reducing blood pressure as a main objective. For Bennett et al the main objective was weight loss but blood pressure was included as a secondary objective.32 In Orsma et al39 the main focus was to improve self- management and health status in patients with type 2 diabetes but improvements in blood pressure were also included as a primary aim.

*Format and delivery*-Mobile phone was the most common mode of delivery in the studies conducted by Yoo36, Piette37 and Orsma.39 Watson et al 35used a website where participants after uploading blood pressure readings through a communications device by phone could view trends and read automated rules-based messages. Nolan et al38 used a series of emails to deliver their intervention while Bennett et al32 offered the choice to participants of using either the study website or an interactive voice response system to monitor their progress. Freidman et al34 used a telephone linked computer system which spoke to patients over the telephone using computer-controlled speech. The patients communicated using the touch-tone keypad on their telephones

*Education*- All of the studies provided additional education via the intervention. This was poorly described in some and ranged from providing tailored behavioural skills training materials, including tailored information on community resources (e.g. public parks, walking groups, and farmers' markets) and distributing a walking kit32 to a simple menu that linked to educational material and self-help tips for lifestyle change.37

*Additional health professional help available* -Three of the studies specified that additional health professional help could be accessed through the intervention if participants required it. Yoo et al36 allowed physicians to use the intervention website to follow participants’ trends in blood glucose levels, blood pressure and body weight changes, and then send individualized recommendations to patients when needed. In the Orsma et al39 study nurses scanned through the status of all intervention patients each week and contacted patients if warranted by their remote data reports. For Bennett et al32 trained community health educators delivered counselling calls monthly during the first 12 months of intervention and bimonthly during the second year. No difference was found in blood pressure reduction between those offering additional help and those not for either SBP, (additional help -3.37 95% CI -0.22 to -6.52 vs no additional help -3.85 95% CI -2.08 to -563) or DBP, (additional help -2.18 95% CI -0.45 to -3.91 vs no additional help -2.58 95% CI 0.95 to -6.11); see supplementary figures 1 and 2.

*Setting* – Five of the studies were set in health care settings, ranging from a hospital and community health care site to outpatient clinics. One study was based in three worksites and one used a number of community sites.

*Duration and intensity* - Only Bennett et al32 (with a duration of 24 months) lasted longer than 10 months, with the shortest duration being 6 weeks.36 No significant difference was found when comparing interventions by duration for SBP (six months or longer -4.35 95% CI -2.10 to -6.60 vs less than six months -3.19 95%CI -1.07 to -5.32) or DBP (six months or longer -3.16 95% CI -0.83 to -6.49 vs less than six months -3.94 95% CI 0.37 to -3.35); see supplementary figures 3 and 4. Intensity of intervention ranged from daily use in three studies to weekly use in two studies. Bennett et al32 had no specific rate of intervention use while Nolan et al38 reduced intensity of use over the duration of the intervention from daily in the first month to bi weekly in month 2 and weekly in months 3 and 4. No significant difference was found for SBP when comparing those interventions which required daily use (-2.73 95% CI -0.35 to -5.12) vs other intervention (-4.46 95% CI -2.44 to -6.49) but daily use interventions had a significantly lower reduction for DBP (daily use -1.29 95% CI -0.04 to -2.53 vs other interventions -3.86 95% CI -2.73 to -4.98);-see supplementary figures 5 and 6.

*Theoretical basis for intervention included in paper* -Three of the studies outlined a theoretical basis for their intervention. Orsma used theInformation-Motivation-Behavioral Skills Model.[[40]](#endnote-40) Nolan et al38 used Prochaska’s Trans theoretical Model to assess readiness to change.[[41]](#endnote-41) Bennett et al32 used theory based principles from the Harvard Cancer Prevention Project, which developed a conceptual framework which articulates pathways by which social context may influence health behaviours.[[42]](#endnote-42) No significant difference was found for SBP when comparing those interventions which included a theoretical basis (-3.02 95% CI -0.79 to -5.24) vs no theoretical basis (-4.41 95% CI -2.26 to -5.5) but theoretical basis recorded no reduction for DBP (no theoretical basis 0.90 95% CI 0.02 to -1.82) while a significant fall was found for no theoretical basis -3.94 (-2.53 to -5.36); see supplementary figures 7 and 8.

**Description of the study population**

Characteristics of the included studies are shown in table 1. Authors differed in how they defined hypertension with Yoo et al36using diagnosis by physician one year previously and Bennett et al 32 33 using use of 1 or more hypertensive medication as a definition. All the remaining studies used blood pressure levels as a definition but these differed for SBP, from >160 mm Hg to >140 mm Hg.

The interventions differed considerably in both their clinical and population characteristics. Mean systolic blood pressure (SBP) at baseline ranged from 128.5 mm Hg32 to 169.5 mm Hg34 and 77.4 mm Hg32 to 88.5 mm Hg39 for diastolic blood pressure (DBP). Mean age of participants also differed considerably from 54.433 to 7734 years.

Males were the majority of participants in just two of the studies36 39 with differences in the percentage of males ranging from 64.836 to 21.0%.34Only two papers recorded the ethnicity of the participants32 34. The method of recording makes comparison difficult but Bennett et al32 recorded that 71.7% of their intervention group were non-Hispanic black compared to Freidman et al34 who had a black population of only 10%. All reviews provided information on education levels with the exception of Nolan38 who reported levels of household income.

**Outcomes**

***Blood pressure***

Watson et al35 did not provide mean changes in either SBP or DBP for those defined as having hypertension so was excluded from the meta- analysis. They reported that in comparing intervention and control patients with hypertension there was no difference in the % who reported either a greater then 10% decline or any decline in SBP, but a significantly higher number of intervention patients did report both a greater then 10% decline in/or any decline for DBP. 35

In total there were 610 intervention and 677 control patients used in the meta-analysis for SBP. Nolan et al divided intervention patients by use of the intervention so we averaged the difference between these groups weighting by the numbers in each group and included in the analysis.38 Figure 2 shows that overall, IDIs significantly reduced SBP with weighted mean difference overall being -3.74 mm Hg (95% CI, -2.19 to -2.58) with no heterogeneity observed (I-squared=0.0%, p=0.990). No significant difference was found between those studies which included self monitoring and those that did not.

Piette et al37 did not report figures for DBP so included numbers were reduced to 521 for intervention patients and 585 for control patients. Figure 3 shows that overall for DBP considerable heterogeneity was recorded (I-squared=80.1%, p=<0.001) with a significant reduction in DBP of -2.37 (95 % CI -0.40 to -4.35%). However when divided into self monitoring vs no self monitoring a much higher reduction was recorded for those studies with self monitoring -4.02 (95% CI -2.93 to -5.12) compared to no self monitoring -0.88 (0.05 to -1.80) with no heterogeneity found for either group.

**Other clinical outcomes**

The included studies also reported on a number of additional clinical indicators. Two studies reported a reduction in weight32 39 with one finding no significant difference.36 Yoo reported significant improvements in HbA1C, total cholesterol, low-density lipoprotein cholesterol and triglyceride levels in the intervention group but no analysis was undertaken on whether the difference for the changes between intervention and control was statistically significant.36 Orsma found that intervention participants achieved, compared with controls and controlling for baseline, a significantly greater mean reduction in HbA1c of - 0.40% vs 0.036%.39 Nolan reported greater significant reduction in the intervention group for pulse pressure (-6.1 mm Hg; vs -3.1 mm Hg) and total cholesterol (-0.24 mmol/L; vs 0.05 mmol/L) for those receiving eight or more emails but significant differences were found for those receiving 1-7 emails.38 No study reported on changes in numbers of additional morbidities.

**Behavioural**

Three papers examined changes in medication adherence/problems all using different methods of measurement. Bennett et al32 used the Hill-Bone Compliance to Hypertension Therapy Scale[[43]](#endnote-43) to assess medication adherence. They found that intervention participants showed significantly greater change in medication adherence at months 6 and 12 but not at 24 months. Friedman et al33 assessed medication adherence using home pill count audit conducted by the field technicians, based on Haynes' protocol.[[44]](#endnote-44) In the Friedman study34, mean adherence improved 17.7% in the intervention group and 11.7% for usual care control subjects (Table 2). Piette et al37 measured medication-related problems using a 7-item index with yes/no responses and found that intervention patients at follow-up had fewer medication-related problems (- 1.1; 95% CI - 1.7, - 0.5), such as uncertainty as to whether their medication is important, worry about the long-term effects of their medication, or confusion due to the complexity of the regimen.

**Affective**

Piette et al37 was the only study to assess impact of the intervention on mental health using a validated Spanish version of the 10-item Center for Epidemiological Studies-Depression Scale. They found that compared with controls, intervention patients at follow-up had lower depression scores (- 2.5).

**Cognitive**

Piette et al37was also the only paper to report on changes in satisfaction with healthcare and with health services related to their hypertension. They found that participants in the intervention group reported a greater overall increase in satisfaction with care and satisfaction with care specifically related to their hypertension.

**Economic**

Only one paper assessed cost effectiveness; Friedman et al34 determined the cost effectiveness of their intervention by calculating the expected operating costs of clinical practice based on the experience during the study, considering all computer and telecommunications costs, facilities charges, supplies, and support personnel for start-up and maintenance of the system. Cost-effectiveness ratios were computed for medication adherence improvement and DBP decrease using simple linear regression analysis. The computed cost per patient user for 6 months of use was $32.50. The cost-effectiveness ratio for adherence change after 6 months of telephone linked computer system use in all hypertensive patients in the study was $5.42 per 1% improvement in adherence. For DBP, the cost-effectiveness ratio for all hypertensive patients was $7.39 per 1 Hg decrease after 6 months of intervention use. Costs were lower for non adherent subjects.

**Quality Appraisal**

Details of the quality appraisal of the included studies can be found in table 2. All of the included studies were randomized controlled trials but the only study where allocation concealment was undertaken was found to have an inadequate randomization procedure.38 Three of the included studies were unclear on how the randomization procedure took place.32 34 36 One study had a dropout rate greater than 20%38 and the eligibility were not clear (so that information had to be requested from the authors).36 Three of the studies did not control for any potential confounders in their analysis. 35 36 37 The majority of the studies were also relatively small in size meaning that even for blood pressure outcomes some were likely to be under powered.

**Discussion**

This systematic review and meta-analysis of seven randomised controlled clinical trials found that the use of interactive digital interventions resulted in better blood pressure control, significantly reducing SBP by 3.74 mm Hg and DBP by 2.2 mm Hg compared to usual care. However, the strength of the evidence is limited due to the small number of studies included, the size of the studies and issues arising from potential bias due to lack of allocation concealment and questions over use of the intention to treat principle in a number of studies. The change in SBP and DBP is similar to that found in previous meta- analyses which have examined the impact of self -monitoring versus no self- monitoring10 17 as well as the impact of face-to-face lifestyle counselling.[[45]](#endnote-45) [[46]](#endnote-46). The change in SBP and DBP found in this study is also similar to that found in analysis of the effect of telemedicine on lowering blood pressure compared to conventional means.[[47]](#endnote-47) [[48]](#endnote-48) [[49]](#endnote-49) However, meta-analysis of the effects of telemedicine have generally suffered from high levels of heterogeneity limiting the generalisability of their results and usefulness in comparison to this study. For SBP no significant difference was found for those interventions which included self-monitoring. In contrast, for DBP a difference was found, with interventions which included self-monitoring recording a reduction of 4.0 mm HG, while those with no self -monitoring showed no significant difference compared to usual care.

The evaluation of other specific intervention components apart from self- monitoring was difficult due to the smaller number of studies involved. However, unlike previous analyses we found no evidence that interventions that lasted longer than six months achieved greater blood pressure reduction than those that lasted less than six months.18 Intensity of the intervention also appeared to have little effect with no significant difference found in blood pressure reduction for SBP while studies with daily use recorded a smaller reduction in blood pressure for DBP compared to interventions with less intensive usage. We also found no evidence that interventions which offered additional professional help achieved greater blood pressure reduction. As interventions which have an additional professional help component to them are likely to be more expensive this may have a significant detrimental effect on the cost effectiveness of these interventions. However, there exists little evidence from other analysis on interventions to lower blood pressure as to whether the effect of the intensity of an intervention or the provision of additional professional help is unique to these interventions. Liu et al suggested that a priority for future trials of preventive internet based interventions is to design and evaluate e-counselling protocols according to theoretically grounded hypotheses.18 However we also found no significant difference in blood pressure reduction for SBP in those studies which included a theoretical basis for the intervention compared with those that did not while those with a theoretical basis failed to record a significant reduction DBP in contrast to studies with no theoretical basis reported. It may be that theoretically grounded hypotheses are simply poorly described in these studies or that other factors may play a more important part in blood pressure reduction.

Included interventions were from a wide range of countries (United States, Korea, Honduras and Mexico, Canada, Finland), suggesting that IDIs were suitable for use across a wide range of health systems. The included interventions featured a range of differing demographics including large differences in age range, ethnicity, and gender, which helps to increase the generalizability of the findings. The range of mean systolic blood pressure (SBP) at baseline was between 128.5 to 169.5 mm Hg and 77.4 to 88.5 mm Hg for diastolic blood pressure (DBP) suggesting that IDIS can also be suitable to address a wide range of hypertensive patients.

The observed magnitude of BP reduction by IDI interventions would have a significant clinical impact at a population level if it was sustained over time. For example a reduction in SBP of 3 mm Hg would be expected to be associated with an 8% reduction in stroke mortality and a 5% reduction in mortality from coronary heart disease.3 However, only one study lasted more than one year limiting the information about how the IDIs perform over a longer period of time, The effect of IDIs on other clinical outcomes is uncertain due to the low number of studies with none assessing the effect on quality of life indicators. However, most studies showed improvements in a wide range of other clinical outcomes potentially adding to the health improvements offered by the use of IDIs. Only one study assessed the cost benefits of its impact making the cost effectiveness of IDI difficult to gauge. There is also no evidence on how intervention effects may differ by socio-economic status or ethnicity. Nevertheless, in addition to the positive clinical effects found for IDIs the criteria used for this study of these interventions, not requiring delivery by a health professional, suggests they could have additional benefits in terms of the time and costs saved for health professionals. The review has a number of limitations. Only a small number of studies fulfilled the criteria and the ,majority were of average quality, had a limited time span and were relatively small in size, meaning that even for blood pressure outcomes most individual studies were likely to be under powered. The small number of studies also meant analysis of the possible effects of specific intervention components was limited. No studies assessed the impact on quality of life and information on cost effectiveness was limited to one study. Information on other clinical outcomes was lacking. One study35 divided intervention patients by use of intervention and did not provide data for all intervention patients, therefore we averaged the changes in these groups which may over or under report the mean change in SBP and DBP in this study. Three further studies33 34 36 did not indicate that the outcome analysis was based on an intention to treat principle and this raised the possibility of bias in the reported results. However, as all papers reported the effect of an intervention versus no intervention it was decided that these studies should remain in the analysis. Strengths of the study include the fact that for SBP all studies showed a consistent outcome with no heterogeneity found. The included studies came from a wide range of different countries with large contrasts found in the demographic and clinical characteristics of the populations suggesting a wide generalizability of the findings.

In conclusion, IDIs can lower both SBP and DBP compared to usual care. Results suggest these findings can be applied to a wide range of health care systems and populations. However, sustainability, long-term clinical effectiveness and the “active components” of these interventions remain uncertain. In our view, the evidence is not yet robust enough to warrant a change in practice or policy. However, if individual patients wish to use an appropriate IDI, clinicians can feel reassured that the impact is likely to be beneficial.

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**Table 2 Population characteristics of study**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Author (Year)  Location | Definition of hypertension | Population  Numbers | Mean  Age (years) | Ethnicity | N (%)  Males | Mean SBP/DBP (SD)  At baseline | Outcomes assessed | Main results |
| Watson\*  (2012)  USA | Eligible participants had raised blood pressure (systolic  blood pressure ≥120 and/or diastolic blood pressure ≥80) on  2 readings taken at least 1 week apart, or self-reported an  existing diagnosis of hypertension (defined as having been  told by a physician on 2 or more occasions that they had elevated blood pressure or being on medication to treat high  blood pressure). | Hypertensive =21, C=14 | N/A | N/A | N/A | N/A | SBP/DBP | No sig difference between Intervention and control of % hypertensive patients recording a >10 mm hg reduction for SBP but sig more intervention recorded >5 mm hg reduction for DBP (51.5 to 26.4). No difference in any decline in SBP but intervention record greater for DBP (72.2 vs 45.2) |
| Yoo  (2009)  Korea | Diagnosis of hypertension by physician at least one year previously | I=57  C=54 | I=57.0  C=59.4 | N/A | I=30 (52.6)  C=35 (64.8) | SBPI=140 (18)  C=138 (18)  DBP  I=84 (10)  C=83 (10) | SBP, DBP, Weight (kg), BMI, waist circumference  Right baPWV, Left baPWV, HbA1, Fasting glucose, HOMA-IR, Total HDL-LDL cholesterol, Triglyceride, Adiponectin, hsCRP, Interleukin-6 | No significant difference was found between intervention and control groups for changes in SBP and DP with both groups showing a significant fall. HbA1c, total cholesterol and LDL-cholesterol levels were  significantly decreased after 3 months in the intervention group  compared with the control group |
| Piette  (2012)  Honduras  Mexico | SBP >130mm Hg if  diabetic or >140mm Hg if non diabetic | I=89  C=92 | I=58.0  C=57.0 | N/A | I=30(33.7)  C=29(31.6) | SBP  I=153.2 (2.8)  C=150.-(2.7)  DBP  N/A | SBP,  Depressive symptoms, Number of medication problems, overall health, satisfaction with care, time since discussing hypertension | Compared  with controls, intervention patients at follow-up had a significantly greater reduction in SBP, reported fewer  depressive symptoms (p = 0.004), fewer medication problems  (p < 0.0001), better general health (p < 0.0001), and greater satisfaction  with care (p £ 0.004). |
| Orsma  (2013)  Sweden | SBP >140mm Hg, or DBP >90mm Hg. | I=24  C=24 | I=62.3  C=61.5 | N/A | I=13 (54.0)  C=13 (54.0) | SBP  I=157.0 (15.6)  C=146.5 (15.3)  DBP  In=88.5 (10.3)  C=84.7 (9.1) | SBP.DBP,  HbA1c, weight (kg), | Intervention participants achieved, compared with controls and controlling for baseline, a significantly greater mean  reduction in HbA1c. and in weight loss but no significant differences in SBP and DBP were observed. |
| Nolan  (2012)  Canada | SBP, 140-159/DBP  90-99 mm Hg, or 160-180/100-110 mm Hg | I(>8 emails)=96  Cl=227 | I=55.7  C=56.7 | N/A | I=27 (27.8)  C=107 (47.1) | SBP  I=143.3 (N/A)  C=139.6 (N/A)  DBP  I=80.9 (N/A)  C=80.1 (N/A) | SBP.DBP, pulse pressure, total cholesterol | subjects receiving ≥ 8 e-counselling vs 0 e-counselling messages (control) demonstrated greater reduction in systolic blood pressure, pulse pressure and total cholesterol, but not diastolic blood pressure. |
| Friedman  (1996)  USA | SBP> 160 mm Hg (DBP) '>90 mm Hg | I =133  C=134 | I=76.0  C=77.0 | Black I=10%, C=11% | I=33 (25.0)  C=28 (21.0) | SBP  I=169.5(N/A)  C=167.0 (N/A)  DBP  I=84.0 (N/A)  C=86.0(N/A) | SBP.DBP, medication adherence, patient satisfaction | Results showed for intervention compared to control significantly greater reduction in SBP and DBP and improved antihypertensive medication  adherence |
| Bennett  (2012)  USA | Use of 1 or more  antihypertensive medication, | I =148  C=146 | I=54.6  C=54.5 | Non-Hispanic white; I=9 (5.0) C=4 (2.2), Non-Hispanic black I=129 (71.7) C=131 (70.8),Hispanic 25 (13.9) 23 (12.4) | I=52 (28.9)  C=63 (34.1) | SBP  I=130.2 (18.9)  C=128.5 (19.7)  DBP  I=79.3 (12.7)  C=77.4 (13.8) | SBP.DBP, medication adherence, weight change, sodium intake, Hill-bone score, appointment keeping, cost effectiveness | Mean systolic blood pressure was not significantly lower in the intervention arm compared with controls. Significant reduction in weight were recorded for the intervention group |

Note:\* Watson paper recorded results only for hypertensive vs controls. All other information was given for all participants which included pre-hypertensive patients) so excluded from this table. N/A=information not available

**Table 3 Description of Interventions**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Author (Year) | Mode of delivery | Health Education  Included | Setting | Self monitoring of blood pressure | Frequency of use | Theoretical basis included in paper | Duration |
| Watson  (2012) | Website | Yes | Hospital and community health care site | Yes | At least once a week | No | 6 months |
| Yoo  (2009) | Mobile Phone | Yes | Worksite | Yes | Daily | No | 3 months |
| Piette  (2012) | Mobile Phone | Yes | Health clinics | Yes | Weekly | No | 6 weeks |
| Orsma  (2013) | Mobile Phone | Yes | Health clinic | Yes | Daily | Yes (Information-Motivation-Behavioural Skills Model) | 10 months |
| Nolan  (2012) | Email | Yes | Outpatient  clinic | No | Daily –month1  Bi-weekly-month 2  Monthly-months 3&4 | Prochaska’s Transtheoretical  Model | 4 months |
| Friedman  (1996)  USA | Phone | Yes | Community site (e.g. senor sites) | Yes | Weekly | No | 6 months |
| Bennett  (2012)  USA | Website/Phone | Yes | Community health sites | No | Random | Yes (From the Harvard Cancer Prevention Program Project) | 24 months |

**Table 4 Quality appraisal for included studies**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Author (Year) | Appropriate  Randomisation  technique | Allocation concealment | Dropout rate <20% | Potential confounders properly accounted for | Were eligibility clear |
| Watson  (2012) | Yes | No | Yes | No | Yes |
| Yoo  (2009) | Not clear | No | Yes | No | No |
| Piette  (2012) | Yes | No | Yes | No | Yes |
| Orsma  (2013) | Yes | No | Yes | Yes | Yes |
| Nolan  (2012) | No | Yes | No | Yes | Yes |
| Friedman  (1996) | Not clear | Not clear | Yes | Yes | Yes |
| Bennett  (2012) | Not clear | No | Yes | Yes | Yes |

**Figure 2 Forest plot of the effect of digital intervention on systolic blood pressure (SBP) reduction, comparing studies using self- monitoring and studies using no self- monitoring.**



**(Squares) indicate the effect size of a study, with 95% confidence interval (CI); (Diamonds) indicate the overall effect size of all studies combined**.

**Figure 2a Funnel plot for SBP**



**Figure 3 Forest plot of the effect of digital intervention on diastolic blood pressure (DBP) reduction, comparing studies using self monitoring and studies using no self monitoring.**



**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

**Figure 3a Funnel plot for DBP**



Supplementary files

**Supplementary figure 1 Forest plot of the effect of digital intervention, comparing studies (with additional professional help available compared to those without for SBP.)**



**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

**Supplementary figure 2 Forest plot of the effect of digital intervention by studies with additional professional help available compared to those without for DBP**

****

**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

**Supplementary figure 3 Forest plot of the effect of digital intervention by duration of intervention (six months or more) compared to those less than six months for SBP.**

****

**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

**Supplementary figure 4 Forest plot of the effect of digital intervention by duration of intervention (six months or more) compared to those less than six months for DBP.**

****

**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

**Supplementary figure 5. Forest plot of the effect of digital intervention by intensity of intervention (daily) compared to those without daily intervention for SBP.**

****

**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

**Supplementary figure 6. Forest plot of the effect of digital intervention by intensity of intervention (daily) compared to those without daily intervention for DBP.**

****

**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

**Supplementary figure 7 Forest plot of the effect of digital intervention by whether study includes theoretical basis compared to those without for SBP.**

****

**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

**Supplementary figure 8. Forest plot of the effect of digital intervention by whether study includes theoretical basis compared to those without for DBP**

**(Squares) indicate the effect size with 95% confidence interval (CI) of a study; (Diamonds) indicate the overall effect size of all studies combined**.

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49. Omboni S, Guarda A. Impact of home blood pressure telemonitoring and blood pressure control: a meta-analysis of randomized controlled studies. Am J Hypertens 2011; 24:989–998.

    Supplementary file 2

    **Example of Search strategy for Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to Present**

    1 exp Hypertension/ 208543

    2 exp Blood Pressure Determination/ 23969

    3 Blood Pressure Monitors/ 1955

    4 (hypertens$ or antihypertens$).ti,ab,kf. 330797

    5 ((high$ or rais$ or elevat$ or increas$ or low or lower$ or decreas$ or reduc$) adj3 (blood pressure$ or bloodpressure$)).ti,ab,kf. 82620

    6 ((blood pressure$ or bloodpressure$) adj3 (above or below)).ti,ab,kf. 1689

    7 ((blood pressure$ or bloodpressure$) adj3 (more than or less than)).ti,ab,kf. 2846

    8 ((high$ or rais$ or elevat$ or increas$ or low or lower$ or decreas$ or reduc$) adj3 (systolic or diastolic or arterial or pulse) adj3 pressur$).ti,ab,kf. 42566

    9 ((systolic or diastolic or arterial or pulse) adj3 pressur$ adj3 (above or below)).ti,ab,kf. 1508

    10 ((systolic or diastolic or arterial or pulse) adj3 pressur$ adj3 (more than or less than)).ti,ab,kf. 2898

    11 or/1-10 440954

    12 (computer or computers).hw. 440776

    13 exp computers/ 68798

    14 exp Computer Systems/ 135702

    15 Online Systems/ 7030

    16 Medical Informatics/ 7980

    17 Medical Informatics Applications/ 1989

    18 Decision Support Techniques/ 11938

    19 Educational Technology/ 1084

    20 Electronics, Medical/ 6126

    21 Audiovisual Aids/ 6146

    22 Telecommunications/ 4247

    23 Multimedia/ 1451

    24 Hypermedia/ 391

    25 Video Games/ 2049

    26 Electronic Health Records/ 5851

    27 exp Cellular Phone/ 4532

    28 Social Networking/ 681

    29 exp Telemedicine/ 15288

    30 Telenursing/ 111

    31 Telephone/ 9062

    32 Information Systems/ 17933

    33 Ambulatory Care Information Systems/ 1160

    34 Software/ 77046

    35 Mobile Applications/ 52

    36 Wireless Technology/ 844

    37 Electronic Mail/ 1809

    38 (computer$ or microcomputer$ or pc or pcs or mac or macs).ti,ab,kf. 293392

    39 (phone$1 or mobile$1 or smartphone$ or handset$ or hand-set$ or handheld$ or hand-held$).ti,ab,kf. 73464

    40 ((electronic$ or digital$ or device$) adj2 tablet$).ti,ab,kf. 124

    41 ((digital$ or electronic$ or communicat$) adj2 device$).ti,ab,kf. 4676

    42 device-based.ti,ab,kf. 1352

    43 (device$ adj2 technolog$).ti,ab,kf. 1068

    44 (PDA or PDAs or personal digital).ti,ab,kf. 6424

    45 mp3-player$.ti,ab,kf. 77

    46 (online or on-line or internet or www or web or website$ or webpage$ or local area network$ or broadband or broad-band).ti,ab,kf. 137944

    47 (wireless or wire-less or wifi or wi-fi or GPS or global positioning system$ or bluetooth$).ti,ab,kf. 21149

    48 (text messag$ or texting or texter$1 or texted or SMS or short messag$ or multimedia messag$ or multi-media messag$ or mms or instant messag$).ti,ab,kf. 7423

    49 (social media$ or facebook or twitter or tweet or tweets).ti,ab,kf. 1860

    50 (webcast$ or webinar$ or podcast$ or wiki or wikis or youtube or you tube or vimeo).ti,ab,kf. 1225

    51 (app or apps).ti,ab,kf. 13007

    52 ((electronic$ or digital$ or device$) adj2 application$).ti,ab,kf. 2727

    53 (iphone$ or i-phone$ or ipad$ or i-pad$ or ipod$ or i-pod$ or palm os or palm pre classic$).ti,ab,kf. 961

    54 (android$ or ios or s40 or symbian$ or windows).ti,ab,kf. 13383

    55 (samsung or nokia or apple$ or zte or lg or huawei or tcl communication$ or lenovo or sony or motorola or audiovox or utstarcom or siemens or blackberr$ or casio or cect or coolpad or fujitsu or htc or just5 or kyocera or lumigon or micromax or mitsubishi or modu or nec or neonode or openmoko or panasonic or pantech or philips or qualcomm or sagem or sanyo or sierra or sk teletech or soutec or trium or toshiba or vidalco).ti,ab,kf. 29212

    56 (video$ or dvd or dvds).ti,ab,kf. 74489

    57 (email$ or e-mail$ or electronic mail$).ti,ab,kf. 7987

    58 (chat room$1 or chatroom$1).ti,ab,kf. 249

    59 (blog$1 or blogging or blogger$ or weblog$1).ti,ab,kf. 699

    60 (bulletin board$1 or bulletinboard$1 or messageboard$1 or message board$1).ti,ab,kf. 401

    61 (software$ or soft-ware$).ti,ab,kf. 82939

    62 (interactiv$ or inter-activ$).ti,ab,kf. 32872

    63 (ehealth$ or e-health$ or mhealth$ or m-health$ or m-learning).ti,ab,kf. 2131

    64 (electronic learn$ or e-learn$).ti,ab,kf. 1174

    65 tele$.ti,ab,kf. 106768

    66 ((digital$ or electronic$ or communicat$ or information$) adj2 technolog$).ti,ab,kf. 11988

    67 ((digital$ or electronic$) adj (intervention$ or therap$ or treatment$ or medicine or medical$ or health$)).ti,ab,kf. 11916

    68 (ICT or ICTs).ti,ab,kf. 2744

    69 medical informatics.ti,ab,kf. 1817

    70 (remot$ adj3 (care or caring or cared or manag$ or consult$ or monitor$ or measur$)).ti,ab,kf. 2887

    71 or/12-70 1202822

    72 11 and 71 16303

    73 randomized controlled trial.pt. 369805

    74 controlled clinical trial.pt. 88072

    75 randomi?ed.ab. 346978

    76 placebo.ab. 152616

    77 clinical trials as topic.sh. 169178

    78 randomly.ab. 210034

    79 trial.ti,ab. 357257

    80 or/73-79 1016989

    81 72 and 80 2277

    82 exp animals/ not humans/ 3917953

    83 ((editorial or news or case reports) not randomized controlled trial).pt. 2179678

    84 case report.ti. 156948

    85 81 not (82 or 83 or 84) 2136

    86 remove duplicates from 85 2058

    87 limit 86 to english language 1916

    **Key to Ovid symbols and commands:**

    $ truncation symbol

    ? wildcard symbol

    ti,ab,kf, searches are restricted to the Title, Abstract, Keyword Heading Word fields

    / searches are restricted to the subject heading field

    sh searches are restricted to the Subject Heading Word field

    exp the subject heading is exploded

    \* the subject heading is searched as a major descriptor only

    pt. search is restricted to the publication type field

    ab. /freq=2 search is restricted to records where the terms occur twice in the abstract

    or/1-3 combine sets 1 to 3 using OR [↑](#endnote-ref-49)