# Does App-based Self-monitoring of Hypertension-related Behaviours Reduce High Blood Pressure?:A Systematic Literature Review with Meta-analyses

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# *Table of Contents*

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## Abstract

**Background:** Self-monitoring of behaviour can support lifestyle modifications; however, we do not know whether such interventions are effective in reducing blood pressure in patients with hypertension.

**Objective:** This systematic review evaluates the extent to which app-based self-monitoring interventions support reductions in blood pressure and changes in hypertension-related behaviours.

**Methods:** A systematic search of six databases identified 4637 articles, of which 226 were included for full text screening. Article screening, study and intervention coding, and data extraction were completed independently by reviewers. Fourteen randomised controlled trials were included in the review.

**Results:** In total 7,365 patients with hypertension were included in the meta-analyses. Results showed that app-based behavioural self-monitoring interventions had a small but statistically significant effect in reducing systolic blood pressure (mean reductions MD=1.57 mmHg 95%CI 0.49 mmHg to 2.66 mmHg and OR=1.60 95%CI 0.74 to 3.42), and in improving medication adherence (mean improvements SMD=0.78, 95%CI 0.22 to 1.34 and OR=3.83, 95%CI 1.25 to 11.76) as an adjunct to usual or enhanced usual care. The review found no effect of interventions in supporting improvements in physical activity, diet, or smoking behaviours. Most interventions consisted of features to enable participants receive feedback on reported health behaviours, report and monitor blood pressure, receive advice by health care providers following the measurements of health behaviours, and many provided tailored support. A subgroup analysis found that tailored self-monitoring behavioural interventions resulted in higher and significant reductions in both systolic and diastolic blood pressure in comparison to non-tailored interventions (SBP = - 2.87 mmHg 95% CI -3.90 to -1.85 vs. SBP = - 0.72 mmHg 95% CI -1.67 to 0.23, Chi2=9.15, P=0.002; DBP = -2.05 mmHg 95% CI -3.10 to -1.01 vs. DBP = -1.32 mmHg 95% CI -2.26 to -0.39, Chi2=9.19, P=0.002).

**Conclusions:** Tailored self-monitoring of hypertension-related behaviours via smartphone apps have modest but clinically significant effects in reducing blood pressure. Future studies should use rigorous methods to explore their effects at supporting changes at both blood pressure and hypertension-related behaviours to inform health care practice. Clinical Trial: not applicable

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# Does App-based Self-monitoring of Hypertension-related Behaviours Reduce High Blood Pressure? : A Systematic Literature Review with Meta-analyses

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**Abstract**

Introduction. Self-monitoring of behaviour can support lifestyle modifications; however, we do not know whether such interventions are effective in reducing blood pressure in patients with hypertension. This systematic review evaluates the extent to which app-based self-monitoring interventions support reductions in blood pressure and changes in hypertension-related behaviours.

Methods. A systematic search of six databases identified 4637 articles, of which 226 were included for full text screening. Article screening, study and intervention coding, and data extraction were completed independently by reviewers. Fourteen randomised controlled trials were included in the review.

Results. In total 7,365 patients with hypertension were included in the meta-analyses. Results showed that app-based behavioural self-monitoring interventions had a small but statistically significant effect in reducing systolic blood pressure (mean reductions MD=1.57 mmHg 95%CI 0.49 mmHg to 2.66 mmHg and OR=1.60 95%CI 0.74 to 3.42), and in improving medication adherence (mean improvements SMD=0.78, 95%CI 0.22 to 1.34 and OR=3.83, 95%CI 1.25 to 11.76) as an adjunct to usual or enhanced usual care. The review found no effect of interventions in supporting improvements in physical activity, diet, or smoking behaviours. Most interventions consisted of features to enable participants receive feedback on reported health behaviours, report and monitor blood pressure, receive advice by health care providers following the measurements of health behaviours, and many provided tailored support. A subgroup analysis found that tailored self-monitoring behavioural interventions resulted in higher and significant reductions in both systolic and diastolic blood pressure in comparison to non-tailored interventions (SBP = - 2.87 mmHg 95% CI -3.90 to -1.85 vs. SBP = - 0.72 mmHg 95% CI -1.67 to 0.23, $Chi^2$=9.15, *P*=0.002; DBP = -2.05 mmHg 95% CI -3.10 to -1.01 vs. DBP = -1.32 mmHg 95% CI -2.26 to -0.39, $Chi^2$=9.19, *P*=0.002).

Conclusion. Tailored self-monitoring of hypertension-related behaviours via smartphone apps have modest but clinically significant effects in reducing blood pressure. Future studies should use rigorous methods to explore their effects at supporting changes at both blood pressure and hypertension-related behaviours to inform health care practice.

**Keywords** self-monitoring, smartphone apps, behaviour change, hypertension, blood pressure

## INTRODUCTION

Hypertension or High Blood Pressure (HBP) affects over one billion adults globally and is a leading risk factor for premature morbidity and mortality [1,2]. However, only about half of adults with hypertension achieve adequate BP control, increasing the cost required for their treatment [3]. In England, hypertension is estimated to cost the National Health Service an excess of £2 billion per year [4]. Although many risk factors contribute to poorly controlled blood pressure, non-adherence to individual prescribed health behaviours, like non-adherence to prescribed medications, low salt intake, high consumption of fruits and vegetables, low alcohol consumption, improvements in physical activity, and stopping tobacco smoking, independently account for the majority of these uncontrolled cases [5-12].

Modifying such health-related behaviours to address the underlying risk factors of hypertension could result in clinically significant health improvements, and reduce morbidity, premature mortality, and treatment health care cost. Practitioners have an important role in prescribing lifestyle modifications, however their time to provide advice about and support adherence to health behaviour change recommendations is limited and expensive [13], and currently there is limited evidence about effective interventions to support health behaviour change in patients with hypertension [14-16].

There is growing interest in the potential of digital interventions as a cost-effective and scalable method to deliver individualized advice to people with long-term health conditions, enabling them to improve adherence to the recommended health behaviour modifications and achieve sustained improvements in health behaviours [17-19]. Smartphone applications (apps), delivered via technologies such as computers, smartphones, tablets, and other hand-held devices can reach large numbers of people, provide ongoing support and in different settings [20]. Smartphone apps appear promising due to their potential to complement physician efforts and engage participants in decision making regarding their health care [21,22]. Users of app-based interventions can receive real-time advice and support about patterns of their health behaviours that impact on their long-term health condition [23], with the potential to eliminate barriers, like recall biases, and better inform shared decision-making during blood pressure checks or other similar health care treatment consultations.

Moreover, reporting and monitoring health behaviours using apps could act as a behaviour change strategy to inform and support the individual to self-regulate their health behaviours, and thus support improvements in clinical outcomes [23,24]. Self-monitoring of behaviour could underpin individual behaviour change through moderating self-regulation processes, for example by prompting monitoring the levels and progress of behavioural performance to achieve adherence to recommended health behaviours and thus bring about positive effects on health behaviours and clinical indicators [24-26]. While app-based self-monitoring of health behaviours can have a direct positive effect on patients' health and an indirect effect on service provision, with the potential to be a cost-effective solution for the health care services, to date there is limited evidence about its clinical effectiveness to support patients treated for hypertension.

Previous systematic reviews have evaluated the impact of app-based interventions to support change in either behaviour or blood pressure [18,27-29]. Further content analysis suggested that such interventions consist of reminders about the behaviour, generic education about the health condition, or features to facilitate social interaction, clinical advice support about medication adjustments or measurements and self-monitoring of blood pressure. However, none of these previous reviews with content analysis have disentangled the effective behavioural strategies that support improvements in condition-related health behaviours and thus reductions in blood pressure in patients treated for hypertension. Thus, we do not know which of these interventions are effective in reducing blood pressure.

This review will examine whether app-based self-monitoring of hypertension-related behaviours reduces blood pressure and improves health behaviours in patients treated for hypertension. The review will also identify the intervention components that supplement self-monitoring interventions and explore whether and to what extent they explain intervention clinical effectiveness.

## METHODS

This systematic literature review involved searches of six electronic databases i.e., MEDLINE via Ovid, Embase via Ovid, Web of Science, PsycINFO, Scopus, Cinahl, and Cochrane Central Register of Controlled Trials (CENTRAL) during August 2021 to identify eligible studies. The search strategy was developed using key words from previous reviews and relevant literature (see full search strategy at supplementary file, Table 1). The review included randomised controlled trials aiming to support behaviour change in people treated for hypertension. Trials involving adults and published after 2000 and in the English language were considered for inclusion. The review was pre-registered with prospero (CRD42019136158).

Title and abstract, and full text screening was implemented independently by four reviewers (AK, VM, SS, MW) and disagreement was discussed with another reviewer (SS). Articles had to meet all the following criteria to be considered for full text screening (a) population was individuals treated for primary or secondary hypertension, (b) intervention consisted of self-monitoring of hypertension-related health behaviours delivered by a smartphone app, (c) intervention aimed to support improvements in blood pressure and health behaviour, (d) comparator was usual care or minimal behavioural intervention, (e) the study included measurements of both blood pressure and health behaviours, and (f) the study was a randomised controlled trial.

Outcome data were extracted for measurements of systolic and diastolic blood pressure, and health behaviours of medication adherence, diet, physical activity, alcohol, and smoking. Outcome data for blood pressure and health behaviours were extracted for baseline and follow up values when feasible, otherwise the follow up values were extracted and included in the analysis. Two reviewers independently extracted outcome data (MW, RH) and disagreement was discussed with another reviewer (AK).

The Taxonomy of Behaviour Change Techniques [30] was used to code the self-monitoring behavioural interventions for their additional intervention strategies. We have also coded the intervention component 'tailoring' for those interventions that delivered different messages to different participants, based on information obtained about them [17], aimed to address the hypothesised mechanism of behaviour change when these were reported (see supplementary file Table 2). Two reviewers independently coded study characteristics and intervention components (VM, SS) and disagreement was discussed with another reviewer (AK). Authors of primary studies were contacted by email for missing or unclear information.

Risk of bias was assessed using the Cochrane Risk of Bias tool version 2, evaluating the risk introduced by measuring the primary outcome of blood pressure [31,32].

**Analysis**

A random effects meta-analysis was conducted to estimate the weighted pooled effect for each of the blood pressure and behavioural outcomes to account for the true effect that may vary across the individual studies [33]. Effect sizes for continuous outcomes were calculated using the mean difference (MD) for the blood pressure and standardised mean difference (SMD) for the behavioural outcome measurements. Effect sizes for dichotomous outcomes were calculated using the odds ratio for both the blood pressure and the behavioural outcomes [34,35].

The $I^2$ statistic was used to estimate heterogeneity and quantify the percentage of variation that is due to heterogeneity rather than chance [33]. Heterogeneity above 60% was considered substantial and thus was explored further. Frequencies were used to summarize the intervention content coded for each of the intervention and comparator groups. Intervention content coded more than 3 times (frequency above 3) was considered for subgroup analyses. We performed subgroup analyses to test for quantitative interactions, that is whether intervention behavioural strategies could explain the variation of the size of the effect.

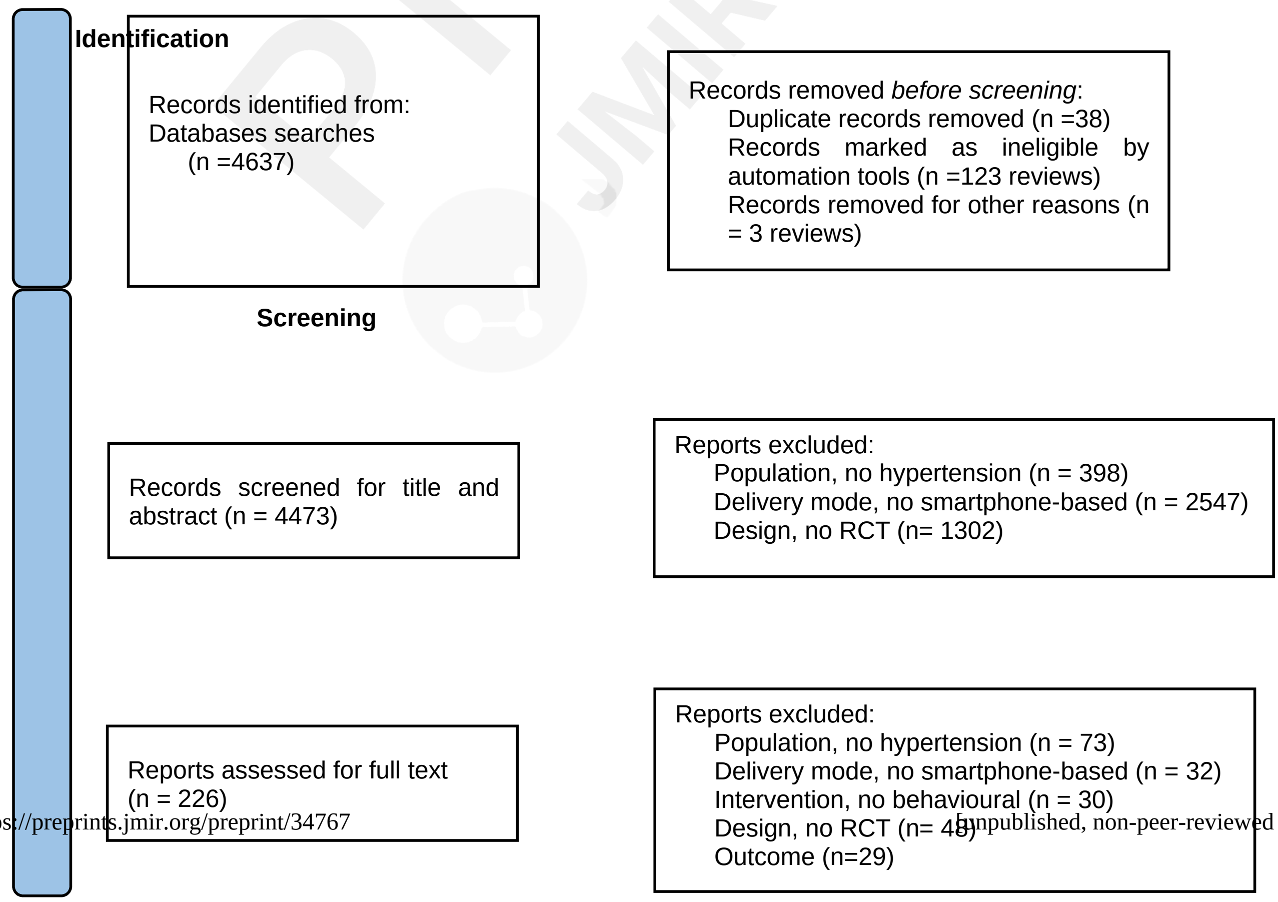
Publication bias was examined by visual inspection of the funnel plot and the Egger test. Meta-analysis was conducted using RevMan version 5.2 [36].

## RESULTS

The systematic search of the six databases identified 4,637 articles of which 226 were included for full text screening. In total fourteen randomised controlled trials with 7,365 participants met all the eligibility criteria and were included in the review with meta-analysis (Figure 1).

Included trials were conducted in the USA (n=5), Australia (n=2), Canada (n=1), China (n=1), New Zealand (n=1), Ghana (n=1), India (n=1), China and India (n=1) and Norway (n=1). Participants (adults above 18 years old) were recruited from primary and secondary health care settings (Table 1).





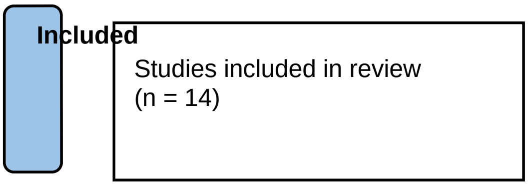



**Figure 1**. Prisma flow chart

## Meta-analysis

**Blood pressure** The meta-analysis suggested that app-based behavioural self-monitoring interventions have a small but statistically significant effect in reducing systolic blood pressure by 1.57 mmHg (95%CI 0.49 mmHg to 2.66 mmHg, n=7253, see Figure 2a) in the experimental group in comparison to the control group, with a similar direction of effect for the two studies that reported changes in the proportion of patients meeting the recommended guidelines for controlled systolic blood pressure (OR=1.60 95%CI 0.74 to 3.42, n=114, Figure 2b).

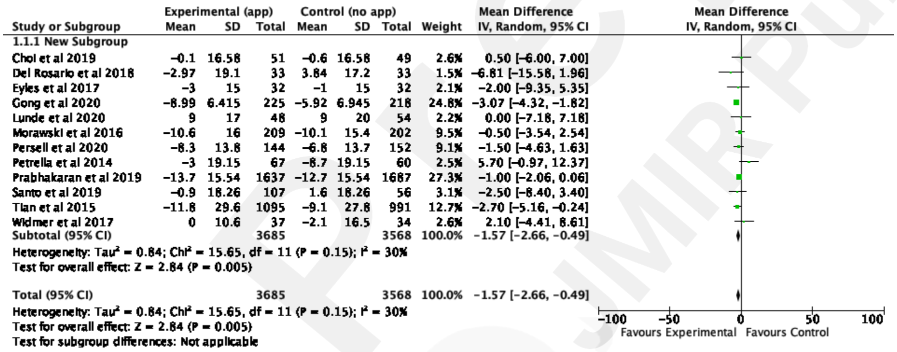



**Figure 2a**. Meta-analysis of continuous outcome measurements for Systolic Blood Pressure

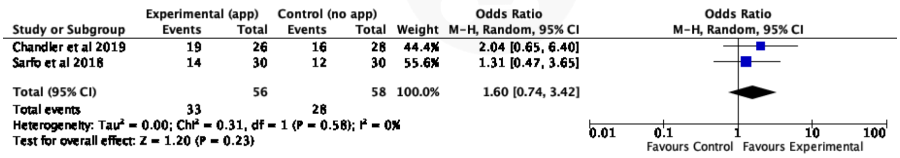



**Figure 2b**. Meta-analysis of dichotomous outcome measurements for Systolic Blood Pressure

A similar direction of effect, but not statistically significant, was found for the impact of the app-based behavioural self-monitoring interventions in reducing diastolic blood pressure. The interventions had a small effect in reducing diastolic blood pressure by 0.39 mmHg (95%CI 1.23

mmHg to 2.01 mmHg, n=1368, Figure 3a) for the continuous outcome analysis. The effect of the interventions in reducing diastolic blood pressure was higher in the experimental than comparator condition for the subsample of studies that reported the proportion of participants meeting the recommended guidelines for diastolic blood pressure (OR=1.41 95%CI 0.66 to 3.01, n=114, Figure 3b); though changes were not statistically significantly different between the two conditions.

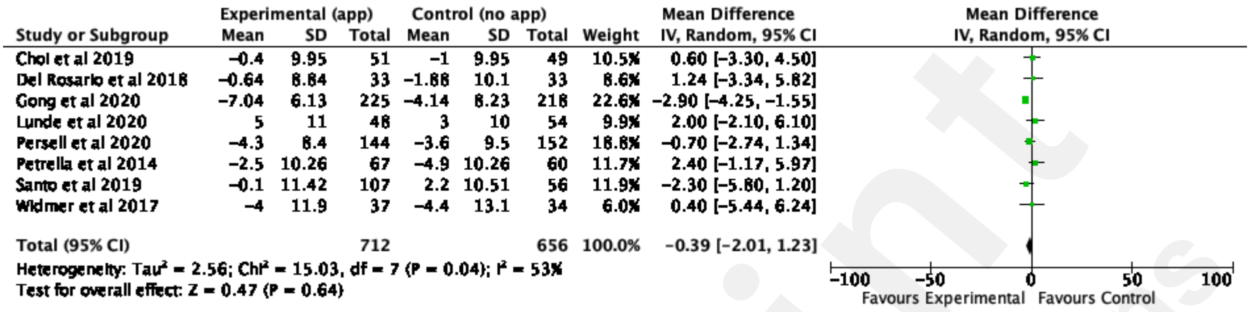



**Figure 3a**. Meta-analysis of continuous outcome measurements for Diastolic Blood Pressure

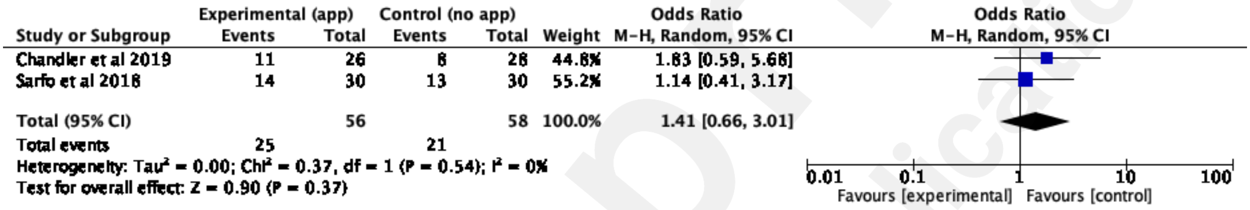



**Figure 3b**. Meta-analysis of dichotomous outcome measurements for Diastolic Blood Pressure

Heterogeneity between studies was low for all Blood Pressure outcome measurements (SBP continuous $I^2$=30%, $Tau^2$=0.84, *P*=0.15; SBP dichotomous $I^2$=0%, $Tau^2$=0, *P*=0.58; DBP continuous $I^2$=53%, $Tau^2$=2.56, *P*=0.15; DBP dichotomous $I^2$=0%, $Tau^2$=0, *P*=0.54), suggesting that there is little variation of effect between studies beyond that due to chance.

**Medication adherence** There was a small but statistically significant effect of the app-based self-monitoring interventions at improving medication adherence in comparison to control, and this effect was supported by both the mean change of medication adherence (SMD=0.78, 95%CI 0.22 to 1.34, n=688, Figure 4a) and by the proportion of participants achieving the recommended threshold for clinically meaningful adherence (OR=3.83, 95%CI 1.25to 11.76, n=6428, Figure 4b).

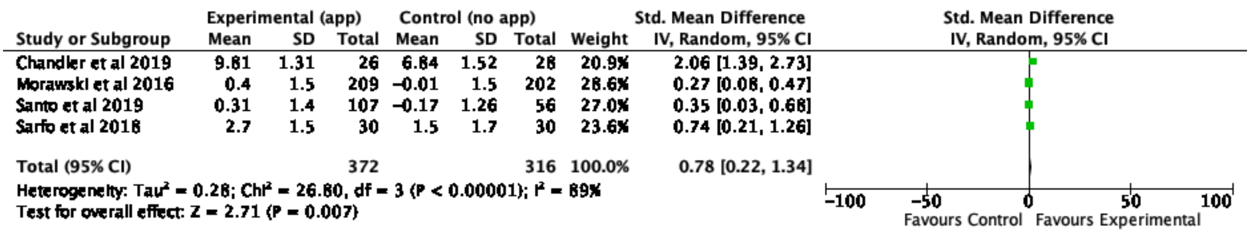


**Figure 4a**. Meta-analysis of continuous outcome measurements for Medication Adherence

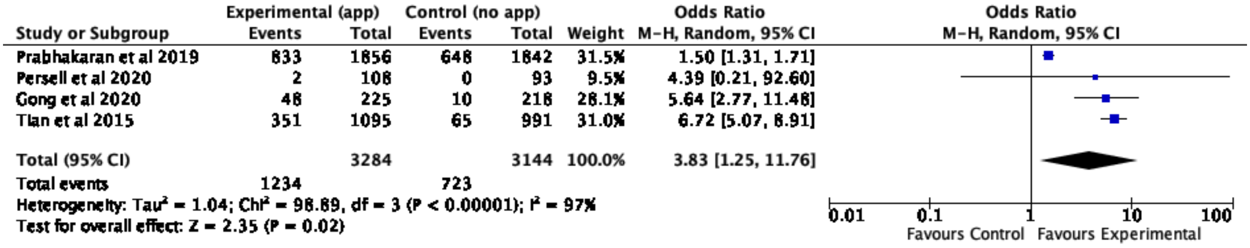



**Figure 4b**. Meta-analysis of dichotomous outcome measurements for Medication Adherence

**Physical activity** The review found no effect of the app-based self-monitoring interventions in improving physical activity, for both the continuous (SMD = 0.35, 95%CI - 0.12 to 0.82, n=303, supplementary file Figure 2a) and dichotomous (OR=1.09, 95%CI 0.57 to 2.07, n=149, supplementary file Figure 2b) outcomes meta-analyses, although only three studies provided data for these analyses.

**Diet** The review included one study for salt consumption and suggested a significant effect of the behavioural intervention on reducing salt intake (SMD = 0.54 95% CI 0.04 to 1.03, n=65, supplementary file Figure 3a); and two studies for healthy diet suggesting no effect of the behavioural interventions on improving diet (SMD = 0.07 95% CI 0.15 to 0.30, n=301, supplementary file Figure 3b). However, these results should be interpreted with caution due to a small number of studies and participants that contributed to the meta-analyses.

**Smoking and alcohol** One study measured smoking and suggested significant improvements in the intervention group compared to control (OR=1.53 95% CI 0.76 to 3.09, n=3698, supplementary file Figure 4). No study on alcohol consumption was found.

**Subgroup analyses**

The most frequent BCTs coded in app-based self-monitoring interventions were feedback on behaviour (n=12), feedback on blood pressure (n=6), goal setting behaviour (n=4), and information about health consequences and generic information about hypertension (n=3). Most of the app-based interventions prompted participants to obtain advice (n=8) by a health care provider following the behavioural measurements, and many (n=5) provided tailored advice to address the underlying mechanisms of behaviour change (see supplementary file Table 2).

Subgroup analysis found that tailored interventions resulted in higher and significant reductions in both systolic and diastolic blood pressure in comparison to non-tailored interventions (SBP = - 2.87

mmHg 95% CI -3.90 to -1.85 vs. SBP = - 0.72 mmHg 95% CI -1.67 to 0.23, Chi$^2$=9.15, *P*=0.002; DBP = -2.05 mmHg 95% CI -3.10 to -1.01 vs. DBP = -1.32 mmHg 95% CI -2.26 to -0.39, Chi$^2$=9.19, *P*=0.002), and the difference between the two conditions was statistically significant (see supplementary file Figure 6 and Figure 7).

## Risk of bias

The risk of bias analyses suggested that studies were of low risk of bias for random sequence generation, allocation concealment and attrition bias. However, due to the nature of the interventions, most studies were assessed as high risk of bias for detection bias and all studies for performance bias (Figure 5).

Inspection of funnel plots and Egger tests suggested low risk of publication bias (supplementary file Figure 5).

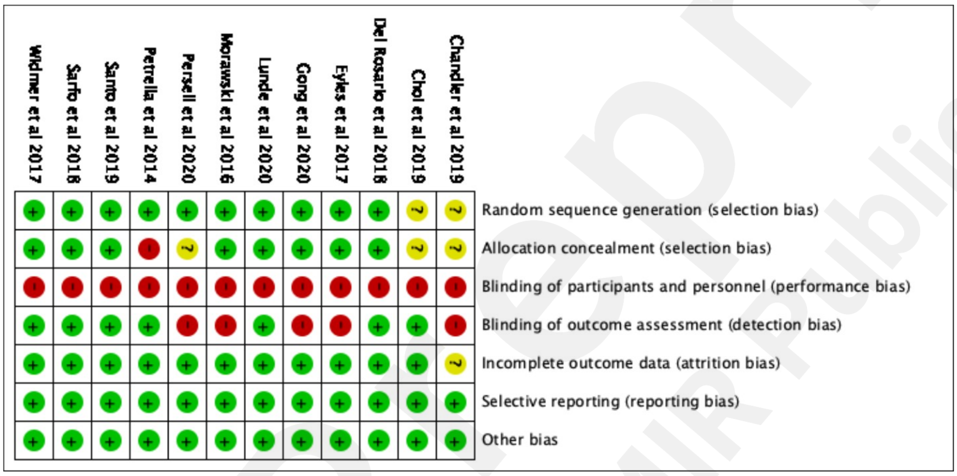



**Figure 5**. Risk of bias assessment for individual randomised controlled trials

Smartphone app-based interventions for hypertension

**Table 1**. Study Characteristics

| Study, Country, Design | Recruitment | Experimental | Control | Outcomes and measurement |
|---|---|---|---|---|
| Chandler et al., 2019[39] USA RCT | Patients contacted via phone and booked in for initial BP screening assessment | Smartphone Medication Adherence Stops Hypertension (SMASH), Bluetooth-enabled BP monitor and an electronic medication tray | Enhanced standard care received text messages including links to PDFs and brief video clips containing healthy lifestyle tips for attention control | Follow up at 1,6 and 9 months Blood pressure: proportion of participants meeting the recommended thresholds for controlled SBP and DBP, change from baseline to 6 months. SBP [ I 19/26 C 16/28] and DPB [ I 11/26 C 8/28] and mean change from baseline to follow up (not estimable); measurement obtained by ambulatory BP readings Medication adherence: self-reported mean difference at 6 months [ I 9.81 (1.31) 26 C 6.84 (1.52) 28]; measurements obtained by Morisky scale |
| Choi et al., 2019[40] USA RCT | Recruited from the cardiology clinic of an academic medical centre | Smartphone app for duration of 6 months | Counselling at 1 and 3 months | Follow up at 1, 3 and 6 months Blood pressure: mean change from baseline to 6 months SBP [ I -0.1 (16.58) 51 C -0.6 (16.58) 49] and DBP [ I -0.4 (9.95) 51 C -1 (9.95) 49]; measured at clinic by RD Diet: mean change of Mediterranean diet from baseline to follow up [ I 0.5 (0.35) 51 C 0.53 (0.35) 49] [a] and proportion of participants meeting guidelines for high compliance with the Mediterranean diet, change from baseline to follow up (not estimable); measured obtained by self-reported 14-items of adherences to Mediterranean diet |
| Del Rosario et al., 2018[41] Australia RCT | Patients referred to hospital for cardiac-related diagnosis were recruited | The Smartphone Technology and Heart Rehabilitation (STAHR) app | No additional advice | Follow up at 6 weeks Blood pressure: mean change from baseline to 6 weeks SBP [ I -2.97 (19.10) 33 C 3.84 (17.2) 33] and DBP [ I -0.4 (9.95) 51 C -1.88 (10.1) 33]; measurement obtained at clinic Physical activity: six-minute walking distance (a clinically established metric to evaluate sub-maximal exercise capacity in CRPs) correlated with the average walking time/day captured at mobile phone (not estimable) |
| Eyles et al., 2017[42] New Zealand RCT | Adverts at supermarkets, hospital, healthcare organization newsletters, and social media; newspapers; posters at | SaltSwitch smartphone app for 4 weeks | Access to cardiac rehabilitation services as per usual care for people with CVD in New Zealand | Follow up at 4 weeks Blood pressure: change from baseline to 4 weeks SBP [ I -3 (15) 32 C -1 (15) 32] and DBP (not estimable) ; blood pressure measurement at the university Diet, salt consumption: mean change of salt consumption from baseline to 4 weeks [ I 0.7 g/MJ (0.52) 33 C 1.0 g/MJ (0.58) 33] [a] ; measurement obtained by household food purchases salt content of household food purchases (g/MJ) |

| | | | | |
|---|---|---|---|---|
| | clinics. | | | Urinary sodium: mean between group difference at sodium at 4 weeks follow up [ I 3534 (536) 32 C 3545 (536) 32] measurement obtained by a random (spot) urine sample. Spot urine concentration was converted into an estimate of 24-hour sodium excretion using the INTERSALT formula |
| Gong et al., 2020[43]<br><br>China<br><br>RCT | Patients diagnosed with primary hypertension were enrolled from 38 hospitals | Yan Fu app | Usual care | Follow up every month, 6 months<br>Blood pressure: mean change from baseline to 6 months [ SBP I -8.99 (6.41) 225 C -5.92 (6.94) 218] and DBP [ SBP I – 7.04 (6.13) 225 C -4.24 (8.13) 218] [a] and mean change in percentage of participants with controlled BP; baseline measurement obtained at clinic follow up using ambulatory blood pressure monitors (for control) or app (for intervention)<br>Medication Adherence: mean change from baseline to 6 months [I 48/225 C 10/218] proportion of medium and high adherence; measurement obtained by 8 item Morisky self-report |
| Lunde et al., 2020[44]<br><br>RCT<br><br>Norway | Patients were recruited from two cardiac rehabilitation centres | Smartphone app | Usual care | Follow up at 12 months<br>Blood pressure: mean change from baseline to 12 months [ SBP I 9 (17) 48 C 9 (20) 54] and DBP [ o 5 (11) 48 C 3 (10) 54]; measurement obtained at clinic<br>Exercise habits: mean change from baseline to 12 months [ I 1.4 (1.5) 48 C 0.6 (1.1) 54] Exercise habits were defined as mean exercise sessions each week for the last year. In this context, an exercise session was defined as structured activity lasting at least 30 min, where you got both sweaty and breathless, and felt like taking a shower afterwards |
| Morawski et al., 2018[45]<br><br>USA<br><br>RCT | Online patient communities, social media, pertinent mobile apps, and targeted adverts. | Medisafe app | Usual care | Follow up at 4, 8 and 12 weeks<br>Blood pressure: mean change from baseline to 12 months SBP [ I -10.6 (16.0) 209 C -10.1 (15.4) 202] and DBP (not estimable); measurement was obtained participants in both treatment groups are contacted and asked to check their blood pressure using the Bluetooth-enabled blood pressure cuff that they were provided at enrolment. Blood pressure is assessed as the average of 2 measurements, taken at least 5 minutes apart<br>Medication adherence: mean change from baseline to 12 weeks follow up [ I 0.4 (1.5) 209 C -0.01 (1.5) 202]; measurement obtained by self-reported Morisky 8 items |
| Persell et al., 2020[46]<br><br>USA<br><br>RCT | Patients were recruited from outpatient primary care clinics | Mobile phone-based tracking application | Remote BP measurements | Follow up at 6 months<br>Blood pressure: mean change from baseline to 6 months SBP [ I -8.3 (13.8) 144 C 6.8 (13.7) 154] and DBP −4.3 (8.4) 144 −3.6 (9.5) 152] ; BP measurement at clinic by research staff<br>Medication adherence: mean change from baseline in proportion of participants fully adherent [ I 2/108 C 0/93] ; measurement obtained by self-reported 4- |

Smartphone app-based interventions for hypertension

| | | | | |
|---|---|---|---|---|
| | | | | day recall<br>Diet: mean change [ I 1.1 (12) 108 C 1.9 (12.08) 93] days per week eating several other food categories (processed meat, fried food, sugar, baked goods or ice cream); measurement obtained by Dietary Approaches to Stop Hypertension diet compliance Questionnaire<br>Physical activity: mean change [ I 5.1 (162) 108 C -16 (163) 93] self-reported at-least-moderate physical activity (days per week times minutes per day) |
| Petrella et al., 2014[47]<br><br>Canada<br><br>RCT | Patients were recruited via adverts printed or radio, word of mouth, community presentations and physician referral. | Tailored exercise program and health monitoring app | Tailored exercise program (similar to interventio n group) | Follow up at 12 weeks<br>Blood pressure: change from baseline to 12 weeks SBP [ I -3 (19.15) 67 C - 8.7 (19.15) 60] and DBP [ I -2.5 (10.2) 67 C – 4.9 (10.2) 60] ; measurement obtained at clinic<br>Physical activity: between group difference in means at 12 week follow up [ I 188.2 (189.5) 67 C 170.3 (161.2) 60] (baseline values not estimable to calculate mean change) ; Exercise compliance was calculated as the percentage of weeks in which at least 150 minutes of exercise was recorded. Participants logged compliance to exercise at the app (experimental) or paper (control). Four measurements in total, one corresponding to each time point, were included as part of the outcome variable |
| Prabhakar an et al., 2019[48]<br><br>India<br><br>Cluster RCT | Patients were recruited by nurses at 20 community health centres | mWellcare system | Enhanced usual care | Follow up at 12 months<br>Blood pressure: mean change from baseline to 12 months SBP [ I -13.7 (15.5) 1842 C -12.7 (15.5) 1856] and DBP [ I -6.5 (10.5) 1842 C -9.5 (10.5) 1856] ; measurement obtained at clinic<br>Tobacco use: change in tobacco use from baseline to 12 months [ I -6% reduction in tobacco users 19.5/1842 C -7% reduction in tobacco users 12.8/1856] number of participants using tobacco; measurement obtained by self-report<br>Alcohol use: mean change from baseline to follow up [ I -3.8% reduction in alcohol users 8.7/1842 C -2.4% reduction in alcohol users 0.3/1856]; measurement obtained using the Alcohol Use Disorder Identification Test<br>Medication adherence: between group difference in days of adherence during the past week at 12 months follow up [ I 648 / 1856 C 833/1842]; measurement obtained by self-report |
| Santo et al., 2018[49]<br><br>Australia<br><br>RCT | Patients with coronary health diseases from a tertiary hospital | Enhanced app | Usual care | Follow up at 3 months<br>Blood pressure: mean change from baseline to 3 months SBP [ I -0.9 (18.26) 107 C 1.6 (18.26) 56] and DBP [ I -0.1 (11.42) 107 C 2.2 (10.51) 56] ; measurement obtained at clinic<br>Medication adherence: mean change from baseline to 3 months [ I 0.31 (1.4) 107 C -0.17 (1.26) 56]; measurement obtained by self-reported Morisky 8 |

Smartphone app-based interventions for hypertension

| | | | | |
|---|---|---|---|---|
| | | | | items |
| Sarfo et al., 2019[50]<br><br>Ghana<br><br>RCT | Outpatient Neurology clinic at Teaching Hospital | smartphone with an App for 3 months | Usual care | Follow up at 9 months<br>Blood pressure: between group difference at 9 months follow up SBP [ I 14/30 C 12/30] and DBP [ I 14/30 C 12/30]; measurement obtained at clinic<br>Medication adherence: mean change from baseline to 9 months follow up [ I 2.7 (1.5) 30 C 1.5 (1.7) 30] [a] ; measured by self-reported 8 items Morisky. Medication possession ratio [ I 22/30 C 22/30] at 9months follow up, measurement obtained by refill prescription data at 3,5 and 9 months |
| Tian et al., 2015[51]<br><br>China and India<br><br>Cluster RCT | Conducted in 47 villages (27 in China and 20 in India). 2,086 patients | Android-powered "app" | Standard care | Follow up at 12 months<br>Blood Pressure: mean change from baseline to 12 months follow up SBP [ I -11.8 (29.6) 1095) C -9.1 (27.8) 991] and DBP (not estimable); measurement obtained at clinic<br>Medication adherence. Mean change of adherent participant [ I 351/1095 C 65/991]; measured by self-reports |
| Widmer et al., 2017[52]<br><br>USA<br><br>RCT | Patients were recruited, consented, and enrolled in a prospective fashion after PCI according to an approved Mayo Clinic IRB protocol | Digital health intervention | Usual care | Follow up at 3 months<br>Blood pressure: mean change from baseline to 3 months SBP [ I (10.6) 37 C -2.1 (16.5) 34] and DBP [ I -4.0 (11.9) 37 C -4.4 (13.1) 34] ; measurements obtained at clinic<br>Diet: scores were calculated by the summation of daily servings of fruits, vegetables, whole grains, and lean proteins with points taken away for daily servings of saturated fats and sweets [ I 1.4 (3.2) 34 C 4.1 (4.1) 34] ; measurement obtained by self-reports<br>Physical activity: mean change of minutes exercises per week [ I 139 (87.7) 34 C 179 (109.1) 34]; measured using self-reported questionnaires<br>Medication adherence: (not estimable) measurement obtained by self- reports<br>Smoking: (not estimable) measurement obtained by self- reports |

[a] data included in meta-analysis
I= intervention group, C=control group. Values are reported as means (SD) or number/total

## DISCUSSION

### Main findings

This systematic literature review with meta-analysis included fourteen trials with 7,365 patients and suggested that app-based self-monitoring of hypertension-related behaviours had small but significant effect in reducing systolic blood pressure in patients prescribed lifestyle treatment for hypertension. Subgroup analyses suggested that tailored interventions had significant effect at reducing both systolic (2.87 mmHg) and diastolic (2.05 mmHg) blood pressure, whereas non-tailored interventions had small and no significant effect. The effect of tailored self-monitoring intervention although modest is clinically meaningful and potentially impactful in reducing morbidity and premature mortality in patients treated for hypertension [37,38].

This study found that app-based behavioural self-monitoring interventions increased the odds of achieving medication adherence by a factor of 3 to 4 in the experimental group compared with control. The significant effect of the app-based interventions in supporting improvements in both blood pressure and medication adherence provides us with confidence that such interventions could be an effective solution to support health behaviour change and thus reduce blood pressure in patients attending blood pressure checks or similar clinical consultations.

The behavioural interventions had positive but not significant effects in supporting reductions in salt consumption and improvements in healthy diet, physical activity, and smoking cessation. Although promising, a small number of studies has contributed to these meta-analyses and thus the results should be treated with caution.

### Strengths and limitations

This review has several strength and limitations. It did not include grey literature or unpublished studies and was limited at searching six publicly accessible databases only. Nevertheless, this review summarizes the currently available evidence to provide the evidence to support that app-based tailored self-monitoring behavioural interventions are effective to reduce systolic blood pressure by on average of 2.87mmHg and diastolic blood pressure by an average of 2.05 mmHg above usual care treatment.

A limitation of the included studies is the use of self-reported measurements of the behavioural outcomes. This might have diminished the validity of the observed intervention effects on health behaviours; thus, future trials should employ valid measures of behavioural outcomes to provide definitive recommendations for practice.

This review has evaluated randomised controlled trials comparing behavioural interventions with usual care or minimal behavioural interventions. We have performed an extensive search strategy and identified all available evidence. We have adopted a rigorous approach to data extraction and intervention coding to generate the results and form recommendations for practice and future intervention development.

**Implications for practice and intervention development**

The app-based self-monitoring behavioural interventions reviewed by this study had a duration from one to twelve months, thus evaluation of sustained effects of the intervention on reductions of blood pressure and impact on overall morbidity and mortality could not be evaluated. Moreover, there was limited evidence about whether and how experimental group participants were engaged with the self-monitoring of health behaviours for a sufficient time and dose to confidently attribute the observed effects to the app-based behavioural interventions. Future research could usefully investigate whether and how individual patterns of app usage might impact on the observed effects. Nevertheless, this review suggested that apps including functions to measure condition-related health behaviours are effective in reducing blood pressure in patients treated for hypertension.

All app-based self-monitoring interventions were implemented as an adjunct to blood pressure checks and most apps included functions for participants to obtain and monitor blood pressure measurements, suggesting that such interventions could be an effective addition to blood pressure check and blood pressure telemonitoring interventions.

The most common behaviour change strategies combined with the behavioural self-monitoring interventions were feedback on health behaviours and feedback on blood pressure, as well as prompts to obtain advice by a health care provider following measurements that required further support and monitoring. Although, none of these additional behavioural strategies individually explained clinical effectiveness, they could have synergistic effect at supporting engagement with self-monitoring processes and thus at generating the observed improvements in health behaviours and reductions in blood pressure. Future studies should use valid measurements of engagement with the intervention strategies, the underpinning of health behaviours and the health behaviours itself to provide more evidence about how self-monitoring of app-based behavioural interventions supports health behaviour change and reductions in blood pressure.

**Conclusion**

This systematic literature review suggested that tailored self-monitoring of hypertension-related behaviours delivered via smartphone apps are effective in reducing blood pressure by an average 2mmHg above and beyond usual care or minimal behavioural interventions. Considering the wide use of smartphone apps and their potential to reach large numbers of people, app-based self-monitoring behavioural interventions could be a cost-effective addition to usual care blood pressure checks in patient treated for hypertension. Future research should use rigorous methods to investigate their direct impact on both health behaviour change and blood pressure, their indirect effects on service provision, and the overall morbidity and premature mortality associated with hypertension.

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**Conflict of interest** none declared

**Availability of data** all data included in this review are reported at table 1 and supplementary files of the manuscript

**References**

1. World Health Organisation (2021). Hypertension. Available from https://www.who.int/health-topics/hypertension#tab=tab_1 [accessed Aug 23 2021]

2. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in hypertension prevalence and progress in treatment control from 1990 to 2019: a pooled analysis of 1201 population-representative studies with 104 million participants. *Lancet*. 2021; 398,10304.

3. Mazzaglia G, Ambrosioni E, Alacqua M, Filippi A, Sessa E, Immordino V, Borghi O, Caputi AP, Cricelli C, Mantovani LG. Adherence to antihypertensive medications and cardiovascular morbidity among newly diagnosed hypertensive patients. *Circulation*. 2009;120:1598-1605.
4. York Health Economics Consortium & School of Pharmacy, University of London. Evaluation of the scale, causes and costs of waste medicines. Report commissioned by

the Department of Health. 2010.

5. Schroeder K, Fahey T, Ebrahim S. Interventions for improving adherence to treatment in patients with high blood pressure in ambulatory settings. *Cochrane Database Syst Rev.* 2004;3. Art. No.: CD004804. DOI:10.1002/14651858.CD004804.
6. He FJ, Li J, Macgregor GA. Effect of longer-term modest salt reduction on blood pressure: Cochrane systematic review and meta-analysis of randomised trials. *BMJ. 2013;* 346:f1325. doi: 10.1136/bmj.f1325
7. Strazzullo P, D'Elia L, Kandala NB, Cappuccio FP. Salt intake, stroke, and cardiovascular disease: Meta-analysis of prospective studies. *BMJ*. 2009;339:b4567. doi: 10.1136/bmj.b4567.
8. John JH, Ziebland S, Yudkin P, Roe LS, Neil HA. Effects of fruit and vegetable consumption on plasma antioxidant concentrations and blood pressure: a randomised controlled trial. *Lancet. 2002*;359:1969–1974.
9. Diaz KM, Shimbo D. Physical activity and the prevention of hypertension. Curr Hypertens Rep**.** 2013;15:659–668. doi: 10.1007/s11906-013-0386-8
10. Huai P, Xun H, Reilly KH, Wang Y, Ma W, Xi B. Physical activity and risk of hypertension: a meta-analysis of prospective cohort studies. *Hypertension*. 2013;62:1021–1026.
11. Roerecke M, Kaczorowski J, Tobe ST, Gmel G, Hasan OS Rehm J. The effect of a reduction in alcohol consumption on blood pressure; a systematic review and meta-analysis. *Lancet Public Health. 2017;*2: 108-120
12. Huxley RR, Woodward M. Cigarette smoking as a risk factor for coronary heart disease in women compared with men: a systematic review and meta-analysis of prospective cohort studies. *Lancet*. 2011;378, 9799, 1297-1305.
13. Health and Social Care Information Centre (hscic). Quality and Outcomes Framework – Prevalence, Achievements and Exceptions Report. England, 2020-21. Published 29 October 2015. Available from https://digital.nhs.uk/data-and-information/publications/statistical/quality-and-outcomes-framework-achievement-prevalence-and-exceptions-data/2020-21
14. Nieuwlaat R, Wilczynski N, Navarro T, Hobson N, Jeffery R, Keepanasseril A, Agoritsas T, Mistry N, Iorio A, Jack S, Sivaramalingam B, Iserman E,Mustafa RA, Jedraszewski D, Cotoi C, Haynes RB. Interventions for enhancing medication adherence. *Cochrane Database Syst Rev s. 2014;*Issue 11. Art. No.: CD000011.

DOI:10.1002/14651858.CD000011.pub4.

15. Acin MT, Rueda J-R, Saiz LC, Parent Mathias V, Alzueta N, Solà I, Garjón J, Erviti J. Alcohol intake reduction for controlling hypertension. *Cochrane Database Syst Rev*. 2020; Issue 9. Art. No.: CD010022. DOI: 10.1002/14651858.CD010022.pub2.
16. Lee LL, Mulvaney CA, Wong YK, Chan ESY, Watson MC, Lin HH. Walking for hypertension. Cochrane Database of Systematic Reviews. 2021;Issue 2. Art. No.: CD008823. DOI: 10.1002/14651858.CD008823.pub2.
17. Kassavou A, Sutton S. Automated telecommunication interventions to promote adherence to cardio-metabolic medications. A meta-analysis of effectiveness and meta-regression of behaviour change techniques. *Health Psy Rev. 2018;12*(1):25–42
18. Armitage LC, Kassavou A, Sutton S. Do mobile device apps designed to support medication adherence demonstrate efficacy? A systematic review of randomised controlled trials, with meta-analysis *BMJ Open. 2020;*10:e032045
19. Berry R, Kassavou A, Sutton S. Does self-monitoring diet and physical activity behaviours using digital technologies support adults with obesity or overweight to lose weight? A systematic literature review with meta-analysis. *Obes Rev*. 2021;22(10):e13306.
20. Ofcom. The text message is 20 years old today. Available from https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2012/the-text-message-is-20-years-old-today [accessed Aug 22 2021]
21. National Institute for Health and Care Excellence (NICE). Medicines adherence: Involving patients in decisions about prescribed medicines and supporting adherence. NICE clinical guideline 76. NICE, London, 2009.
22. World Health Organisation. Global Strategy on Digital Health. Available from https://apps.who.int/iris/bitstream/handle/10665/344249/9789240020924-eng.pdf [accessed Aug 23 2021]
23. Spauldin EM, Marve FA, Piasecki RJ, Martin SS, Allen JK. (2021). User engagement with smartphone apps and cardiovascular disease risk factor outcomes: Systematic review. *JMIR Cardio*. 2021;5 (1):e18834.
24. French DP, Sutton S. Reactivity of measurement in health psychology: how much of a problem is it? What can be done about it? *Br J Health Psy. 2020;*15: 453-468.
25. McCambridge J, Kypri K. Can simply answering research questions change behaviour? Systematic review and meta-analyses of brief alcohol intervention trials.

*PloS One. 2011;*6:e23748.

26. McCambridge J, Witton J, Elbourne DR. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *J Clin Epidemiol. 2014;*67:267-277.
27. Haase J, Farris KB, Dorsch MP. Mobile Applications to Improve Medication Adherence. *Telemed J E Health*. 2017;23(2):75-79.
28. Park JYE, Li J, Howren A, Tsao NW, De Vera M. Mobile Phone Apps Targeting Medication Adherence: Quality Assessment and Content Analysis of User Reviews. *JMIR Mhealth Uhealth*. 2019;7(1):e11919
29. Alessa T, Hawley MS, Hock ES, de Witte L. Smartphone Apps to Support Self-Management of Hypertension: Review and Content Analysis. *JMIR Mhealth Uhealth*. 2019;7(5):e13645
30. Michie S, Richardson M, Johnston M, Abraham C, Francis J, Hardeman W, Eccles MP, Cane J, Wood CE. The behaviour change technique taxonomy (v1) of 93 hierarchically clustered techniques. Building an international consensus for the reporting of behaviour interventions. Ann Behav Med. 2013;46(1):81-95.
31. Higgins J, Savović J, Page M, Elbers R, Sterne J. Chapter 8: Assessing risk of bias in a randomized trial | Cochrane Training. Cochrane Training. https://training.cochrane.org/handbook/current/chapter-08. Accessed June 22, 2020.
32. RoB 2: A revised Cochrane risk-of-bias tool for randomized trials | Cochrane Bias. https://methods.cochrane.org/bias/resources/rob-2-revised-cochrane-risk-bias-tool-randomized-trials [Accessed June 16 2020]
33. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *Br Med J*. 2003;327(7414):557-560.
34. Higgins J, Li T, Deeks J. Chapter 6: Choosing effect measures and computing estimates of effect | Cochrane Training. Cochrane Training. https://training.cochrane.org/handbook/current/chapter-06 [Accessed June 14 2020]
35. Deeks J, Higgins J, Douglas A. Chapter 10: Analysing data and undertaking meta-analyses | Cochrane Training. Cochrane Training.
36. RevMan | Cochrane Training. https://training.cochrane.org/online-learning/core-software-cochrane-reviews/revman [Accessed July 14 2020]
37. Lawes CM, Vander Hoorn S, Rodgers A. International Society of Hypertension. Global burden of blood-pressure-related disease. *Lancet.2008;371*:1513–1518

38. Lewington S, Clarke R, Qizilbash N, Peto R, Collins R; Prospective Studies Collaboration. Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. *Lancet. 2002;360*:1903–1913.
39. Chandler J, Sox L, Kellam K, Feder L, Nemeth L, Treiber F. Impact of a culturally tailored mHealth medication regimen self-management program upon blood pressure among hypertensive Hispanic adults. *Inter J Env Res Public Health*. 2019;16:1226.
40. Choi BG, Dhawan T, Metzger K, Marshall L, Akbar W, Jain T, Young H, Katz R. Image-based mobile system for dietary management in an American cardiology population. Pilot randomised controlled trial to assess the efficacy of dietary coaching delivered via a smartphone app versus traditional counselling. *JMIR mHealth uHealth*. 2019;7(4):e10755
41. Del Rosario MB, Lovell NH, Fildes J, Holgate K, Yu J, Ferry C, Schreier G, Ooi S, Redmond S. Evaluation of an mHealth-based adjunct to outpatient cardiac rehabilitation. *Cochrane Database Syst Rev*. 2018;22(6):1938.
42. Eyles H, McLean R, Neal B, Jiang Y, Doughty R, McLean R, Mhurchu CN. A salt-reduction smartphone app support lower-salt food purchases for people with cardiovascular disease. Findings from the SaltSwitch randomised controlled trial. *Eur J Prev Cardiol*. 2017;24(13):1435-1444.
43. Gong K, Yan YL, Li Y, Du J, Wang J, Han Y, Zou Y, Zou XY, Huang H, She Q. Mobile health applications for the management of primary hypertension. A multicentre randomised controlled trial. *Medicine Open*. 2020;16:1-5.
44. Lunde P, Bye A, Bergland A, Grimsmo J, Jarstad E, Nilson BB. Long-term follow up with a smartphone application improves exercise capacity post cardiac rehabilitation. A randomised controlled trial. *Eur J Prev Cardiol*. 2020;
45. Morawski K, Ghazinouri R, Krumme A, Lauffenburger JC, Zhigang L, Durfee E, Oley L, Lee J, Mohta N, Haff N, Juusola J, Choudhry N. Association of a smartphone application with medication adherence and blood pressure control. The MediSAFE-BP randomised clinical trial. *JAMA Intern Med*. 2018;178(6):802-809.
46. Persell S, Peprah Y, Lipiszko D, Lee JY, Li J, Ciolino JD, Karmali KN, Sato H. Effect of home blood pressure monitoring via a smartphone hypertension coaching application or tracking application on adults with uncontrolled hypertension. A randomised clinical trial. *JAMA Open*. 2020;3(3):e200255
47. Petrella RJ, Stuckey MI, Shapiro S, Gill DP. Mobile health, exercise and metabolic

risk. A randomised controlled trial. *BMC Public Health*. 2014;14:1082.

48. Prabhakaran D, Jha D, Prieto-Merino D, Roy A, Singh K, Ajay VS, Jindal D, Gupra P, Kondal D, Goenka S, Jacob PD, Singh R, Kumar P, Perel P, Tandon N, Patel V. Effectiveness of an mHealth-based electronic decision support system for integrated management of chronic conditions in primary care. The mWellcare cluster-randomised controlled trial. *Circulation*. 2019;139:380-391.
49. Santo K, Singleton A, Rogers K, Thiagalingam A, Chalmers J, Chow CK, Redfren J. Medication reminder applications to improve adherence in coronary heart disease. A randomised clinical trial. *BMJ*. 2018;105:323-329.
50. Sarfo FS, Treiber F, Gebregziabher M, Adamu S, Nichils M, Singh A, Obese V, Sarfo-Kantanka O, Sakyi A, Adu-Dark0 Nyantakyi, Tagge R, Agyei-Frimpong M, Kwartend N, Badu E, Mensah N, Ampofo M, Jenkins C, Ovbiagele B. Phone-based interventions for blood pressure control among Ghanaian stroke survivors. A pilot randomised controlled trial. *Inter J Stroke*. 2019;14(6):630-638.
51. Tian M, Ajay V, Dunzhu D, Hameed S, Li X, Liu Z, Li C, Chen H, Cho K, Li R, Zhao X, Jindal D, Rawal I, Ali Mk, Peterson ED, Ji J, Amarchand R, Krishan A, Tandon N, xu LQ, Wu Y, Prabhakaran D, Yan L. A cluster randomised controlled trial of a simplified multifaceted management program for individuals at high cardiovascular risk (SimCard trial) in rural Tibet, Chine and Haryana, India. *Circulation*. 2015;132(9):815-824.
52. Widmer JR, Allison T, Lennon R, Lopez-Jimenez F, Lerman LO, Lerman A. Digital health interventions during cardiac rehabilitation. A randomised controlled trial. *Am Heart J*. 2017;188:65-72.

Smartphone app-based interventions for hypertension

# Supplementary Files

# Multimedia Appendixes

Untitled.
URL: http://asset.jmir.pub/assets/f0d948826f92f98615566291c68f3712.docx

# CONSORT (or other) checklists

PRISMA checklist.
URL: http://asset.jmir.pub/assets/956d3e711b367a20ccf811ddf74100a8.pdf