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Interventions to promote physical distancing behaviour during infectious disease pandemics or epidemics: A systematic review

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ABSTRACT

Objectives: Physical distancing, defined as keeping 1–2m apart when co-located, can prevent cases of droplet or aerosol transmitted infectious diseases such as SARS-CoV2. During the COVID-19 pandemic, distancing was a recommendation or a requirement in many countries. This systematic review aimed to determine which

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interventions and behavior change techniques (BCTs) are effective in promoting adherence to distancing and through which potential mechanisms of action (MOAs).
Methods: Six databases were searched. The review included studies that were (a) conducted on humans, (b) reported physical distancing interventions, (c) included any comparator (e.g., pre-intervention versus post-intervention; randomized controlled trial), and (d) reported actual distancing or predictors of distancing behavior. Risk of bias was assessed using the Mixed Methods Appraisal Tool. BCTs and potential MoAs were identified in each intervention.
Results: Six articles (with seven studies and 19 comparisons) indicated that distancing interventions could successfully change MoAs and behavior. Successful BCTs (MoAs) included *feedback on behavior* (e.g., *motivation*); *information about health consequences, salience of health consequences* (e.g., *beliefs about consequences*), *demonstration* (e.g., *beliefs about capabilities*), and *restructuring the physical environment* (e.g., *environmental context and resources*). The most promising interventions were proximity buzzers, directional systems, and posters with loss-framed messages that demonstrated the behaviors.
Conclusions: The evidence indicates several BCTs and potential MoAs that should be targeted in interventions and highlights gaps that should be the focus of future research.

1. Introduction

The COVID-19 pandemic has caused over 5.9 million deaths globally at the time of writing (Feburary, 2022; John Hopkins University, 2021). SARS-CoV-2 (the virus that causes COVID-19) is higher in transmissibility than other epidemic viruses (e.g., SARS-CoV, MERS-CoV) with a reproductive number (i.e., the average number of people an infected person infects) of 2 to 3.58 (this is higher than the 1.7 to 1.9 and < 1, for SARS-CoV and MERS-CoV respectively; Zhu et al., 2020). For eleven months in 2020 there was no vaccine for the SARS-CoV-2 virus. This meant that the highly transmissible virus needed to be solely controlled through non-pharmaceutical methods (e.g., wearing face-coverings, avoiding crowded places, staying at home, physically distancing from others, cleaning hands, testing, self-isolating if infected) that involved individuals changing their behavior. Even with a good uptake of vaccines these behaviors are important to keep transmission rates low (Vilches et al., 2019).

The risk of spreading SARS-CoV-2 is particularly high when people are in the same location (CDC, 2022). Physical distancing (i.e., staying at least 1–2 m apart from people when co-located), reduces the risk of infection from aerosols and droplets entering the eyes, nose or mouth when an infected person talks, coughs or sneezes (CDC, 2022). Indeed, one review found that SARS-CoV-2 transmission is reduced with physical distancing of 1m or more compared with closer than 1m (Chu et al., 2020).

Many governments and health agencies have recommended people adhere to a physical distance of between 1m (WHO, 2020) and 2m (NHS, 2021) from people who are not in their household. Desirable spatial distance varies considerably across social and environmental contexts (e.g., familiarity of person, standing vs. seated, indoors vs. outdoors, occupation) despite the desirability of personal space (Sommer, 1969). For example, typical social interaction happens at an average of 135.1cm for formal interaction and 91.7cm for interaction with friends (Sorokowska et al., 2017).

Policymakers and researchers often use the terms social distancing or physical distancing to describe several behaviors: Staying at least 1–2m apart from others when co-located and crowd avoidance (which is made up of several behaviors such as avoiding crowded places, working from home, only leaving the house for essential purposes and exercise, ordering groceries online). These behaviors have the same goal of limiting contact to reduce transmission of the virus and may have some of the same predictors (e.g., fear of contracting COVID-19). However, the suite of behaviors linked to crowd avoidance differ from staying at least 1–2m apart from others. Crowd avoidance is likely to be impeded by structural barriers, such as type of occupation and not having internet access, that do not affect the ability to stay at least 1–2m apart. Likewise, staying at least 1–2m apart is likely to be impeded by the actions of the others in the vicinity (Hoeben et al., 2021) that will not affect adherence to crowd avoidance. As such, interventions designed to promote crowd avoidance and physical distancing are likely to have different antecedents and require different approaches. Moreover, staying at least 1–2m apart when co-located is a more pressing public health concern – a survey found that adherence to crowd avoidance was 90% but adherence to staying 1–2m apart was only around 66% (Coroiu et al., 2020). We have thus focused on one physical distancing behavior that is staying at least 1–2m apart from others when co-located (we refer to this as physical distancing throughout).

Levels of adherence to physical distancing regulations during the COVID-19 pandemic have been varied; between 30.4% and 94.6% of people surveyed reported keeping a physical distance from others (Coroiu et al., 2020; Dohle et al., 2020; Nivette et al., 2021; Norman et al., 2020; ONS, 2021). There were differences in adherence between countries (Dohle et al., 2020; Nivette et al., 2021; Norman et al., 2020; ONS, 2021) and contexts (e.g., indoors vs. outdoors; Norman et al., 2020). Predictors of physical distancing were: beliefs (e.g., higher trust in politics and science was positively correlated with adherence; Dohle et al., 2020); quality of messages (e.g., the clarity of rules predicted distancing early in the pandemic; Reinders Folmer et al., 2020a) and level of infection in society (i.e., high infection levels were related to increased distancing; Reinders Folmer et al., 2020b). It is therefore important to understand what influences and how to influence distancing behaviors to design effective behavior change interventions (see O'Connor et al., 2020).

To design effective behavior change interventions, it is essential to identify exactly what behavior needs to change and the influences on said behavior (i.e., constructs from the Theoretical Domains Framework (TDF); Cane et al., 2012; and Behavior Change Wheel COM-B model, Michie et al., 2014). The strategies to change these constructs must then be determined (i.e., the intervention functions and policy categories), alongside the behavior change techniques (BCT: Michie et al., 2013), and how to deliver that BCT. For the target behavior of physical distancing a relevant domain to target could be *social influences* (i.e., the social environment, support, norms, and culture). Within the domain of social influences, a relevant theoretical construct is *social norm,* which can be changed by targeting the intervention function of *modelling* (i.e., providing examples for people to emulate). Modelling can be achieved by using the BCT of *demonstration of the behavior* that can be delivered by a poster showing two people distancing using the length of a car to ensure they are 2m apart.

Longitudinal survey studies (Hagger et al., 2020; Hamilton et al., 2020; Norman et al., 2020; Rozendaal et al., 2020; Van Bavel et al., 2020; Vignoles et al., 2021), guidance documents, and position papers (e.g., Bonell et al., 2020; Drury et al., 2021a; SPI-B, 2020; Templeton et al., 2020) have identified several predictors that influenced physical distancing behavior. These predictors are associated with the theoretical domains of *social influences, beliefs about capabilities, beliefs about consequences, behavioral regulation*, and *knowledge*. The survey studies proposed BCTs (e.g., *information about others' approval, framing/reframing,*

feedback on behavior, restructuring the physical environment; information about health consequences, salience of health consequences, habit formation, and prompts and cues) that could be used in interventions (Hagger et al., 2020; Hamilton et al., 2020; Norman et al., 2020; Rozendaal et al., 2020). However, interventions that allow comparisons between the presence and absence of intervention components are needed to identify relevant theoretical domains, intervention functions, and determine which BCTs are effective.

It is also important, during intervention development, to identify the potential Mechanisms of Action (MoAs) that BCTs might influence (Moore and Evans, 2017; Carey et al., 2019) to create a logic model for how the intervention works. The Theory and Techniques Tool (Carey et al., 2019; Connell et al., 2018; Johnston et al., 2020) was developed from a synthesis of the literature, consensus, and triangulation studies to determine which potential MoA each BCT influences and the strength of that evidence.

1.1. The present study

Although the survey evidence identifies potential theoretical domains and BCTs to target, we do not know (a) if interventions are effective at promoting the performance of physical distancing during a pandemic; (b) what the most effective components of interventions are (e.g., behavior change techniques; modes of delivery); (c) what are the likely theoretical domains, intervention functions and MoAs; (d) for whom are the interventions most effective; and (e) the circumstances in which the interventions work best (e.g., phase of pandemic; other restrictions such as lockdown; infection rate; case fatality ratio). This review aimed to systematically review the evidence to determine the effectiveness and methodological quality of interventions to promote physical distancing and to explore moderators of effects on behavior.

2. Methods

The review was pre-registered on PROSPERO (CRD42021230821). The PRISMA guidelines (Page et al., 2021) were followed and the checklist is included in the Supplementary Materials Table S1.

2.1. Search strategy and selection criteria

Searches for published and unpublished studies were performed on six databases between January to February 2021 using PubMed, APA PsycInfo, Web of Science (see Supplementary materials for the full list of Web of Science databases), PsyArXiv, MedRXiv and the Open Science Framework with no restriction on date. Search filters used were for behavior (e.g., physical distancing, social distancing), study type (e.g., intervention, trial or experiment) and virus related (e.g., COVID, coronavirus, SARS, MERS, H1N1, Ebola, influenza or swine flu pandemic, epidemic) based on search terms used in previous reviews (Lawes-Wickwar et al., 2021). MeSH terms were used where available. See Supplementary Materials for full search terms for each database. Additional studies were located using ascendancy (using Google Scholar) and descendancy approaches.

Using PICO (population, intervention, comparator, outcome), studies were included if they (a) included any human population, (b), reported interventions to promote physical-distancing (i.e., those that focus on distancing when people are co-located in the same physical space, e.g., keeping at least 1–2m apart) in any setting (c) included any comparator (e.g., pre-intervention behavior, alternative intervention, a control group, a measurement only group), and (d), the outcomes reported were performance of physical-distancing behavior (e.g., observational measures of number of people distancing vs not distancing; self-reported frequency or quality of distancing behavior), a predictor of behavior (i.e., a MoA or theoretical construct or variable that may influence behavior: e.g., self-efficacy, intentions, willingness, attitudes, norms) or outcomes of behavior (e.g., number of infections). The included studies could be for any date and of any study design (e.g., randomized controlled trials; pre-post studies; nonrandomized controlled trials; natural experiments).

3. Screening

Each reference was screened by two authors using Rayyan referencing software - screening was conducted by 18 authors (all with a PhD and/or MSc in psychology). At the title/abstract screening stage any that were marked as 'include' by at least one screener were reviewed at the full text stage. Any that were marked 'maybe' by at least one screener were further assessed by the first author who decided whether to include for the full text stage. Full texts were screened by two additional authors (TE, DG) and disagreements were resolved through discussion with the two authors (there was 17% disagreement in the full texts).

3.1. Data extraction

Data were extracted by the first author using a coding frame (see Supplementary Table S2 for coding frame and full details of study characteristics) developed by two authors (TE, DG – both had PhDs in Psychology and expertise in reviewing). For each study, the following were recorded: study type (e.g. randomized controlled trials; pre-post studies; non-randomized trials; natural experiments); context (e.g., country of data collection, date of data collection, public health restrictions in place at the time, phase of the pandemic); sample (e.g., *N*, population, gender, age); intervention description (e.g., setting, description of delivery); comparison (e.g., type of control or alternative intervention, description of delivery, BCTs, and a summary of the findings (including effect sizes and whether measure of distancing was indoors or outdoors). Two methods of measuring effectiveness were used (a) Cohen's *d* was calculated where possible to report the size of the intervention's effect and (b) *p* values were used to determine the significance of differences between the intervention and comparison.

To aid readers interested in intervention design we identified BCTs (i.e. the active ingredient in interventions) included in the intervention (e.g., feedback on behavior), the potential MoAs (i.e. a construct that the BCT influences that may subsequently influence behavior; e.g., feedback processes) through which the BCTs might work, the theoretical domains (i.e. what needs to change; e.g., knowledge), and the intervention functions (i.e the means by which to change the behavior; e.g., education).

BCTs were identified using the Behavior Change Technique Taxonomy Version 1 (BCTTv1; Michie et al., 2013), which is a 93-item taxonomy of behavior change techniques that is widely used in describing interventions. The theoretical domains were identified using the results of an expert consensus study that identified domains related to BCTs (Cane et al., 2015). Intervention functions related to each BCT were identified by using a review of interventions and an expert consensus exercise (Michie et al., 2014). The MoAs related to each BCT were identified using the Theory and Technique Tool (Carey et al., 2019; Connell et al., 2018; Johnston et al., 2020), which is an atheoretical list of MoAs that are linked to BCTs. Policy categories were identified using the Behavior Change Wheel definitions (Michie et al., 2014).

Risk of bias was assessed using the Mixed Methods Assessment Tool (MMAT, Hong et al., 2018). This tool was chosen as it allows for the assessment of the varied study designs that were potentially included in this review. The tool uses two screening questions on the research question and suitability of data collection with five follow-up questions depending on design (see Table 2) – all manuscripts, supporting materials, and pre-registrations were checked for details. For RCTs, appropriate randomization was assessed for details of how this was managed (e.g., via computer algorithm). Comparable groups at baseline were assessed by examining randomization checks and tables of baseline information, if provided, to determine if any large differences were likely. Complete outcome data of at least 80% was assessed by reported

drop-outs, exclusions, and comparing baseline *N*s with those reported in the results for the outcome variables (i.e., *n*s, *df*s). Whether the outcome assessor was blinded (i.e., participants if self-report measures used, intervention provider if they were involved in measurement) was evaluated by looking for information about blinding. Participants' adherence to the assigned intervention (i.e., exposed to and continued with intervention to follow up, no crossover to comparator or another intervention) was assessed by looking at the methods section to assess if they had been exposed to the intervention or they could have avoided the intervention.

For non-randomized trials, the extent to which the sample was representative of the target population was assessed by scrutinizing descriptions of the sample, the target population, and descriptions of attempts to achieve representativeness. The appropriateness of the measurements included having a clear definition of the measure, accurately measured, and with validated and reliable instruments. Complete outcome data was assessed as described above. Controlling for confounding variables was assessed by identifying potential confounding variables and seeing if these were controlled for in the study. Assessment of if the intervention was administered as intended was from the descriptions of the intervention and reports of deviations from this procedure.

For quantitative descriptive studies, the quality of the sampling strategy was gauged by assessing how closely the method of selection was associated with the research question. The sample's representativeness of the target population was assessed as described above. The appropriateness of the measurements was assessed as described above. The non-response bias was judged by evaluating non-responders against responders. The appropriateness of the statistical analysis was assessed through the stated details of the analysis, the justification, and any limitations recognized.

Risk of bias was assessed independently by two of the authors (TE and DG or APK) and disagreements were discussed until agreement was reached (initial agreement was between 65 and 100%).

The summary of findings, effect sizes, and BCTs, were extracted/calculated by the first author and by a second data-extractor (LMB or SFA). Study authors were contacted for missing information.

A narrative description of studies and a meta-analysis was planned (PROSPERO CRD42021230821); yet, due to the small number of effect sizes identified for each outcome, and problems with the independence of these effect sizes, a narrative synthesis only was undertaken. The key purpose of the review was to assess the evidence for each type of intervention to aid governments, policymakers, and organisations to evaluate the options. We therefore reported the results by type of intervention (legislation, environmental/social planning, regulation, communications and marketing). To inform intervention design, we also

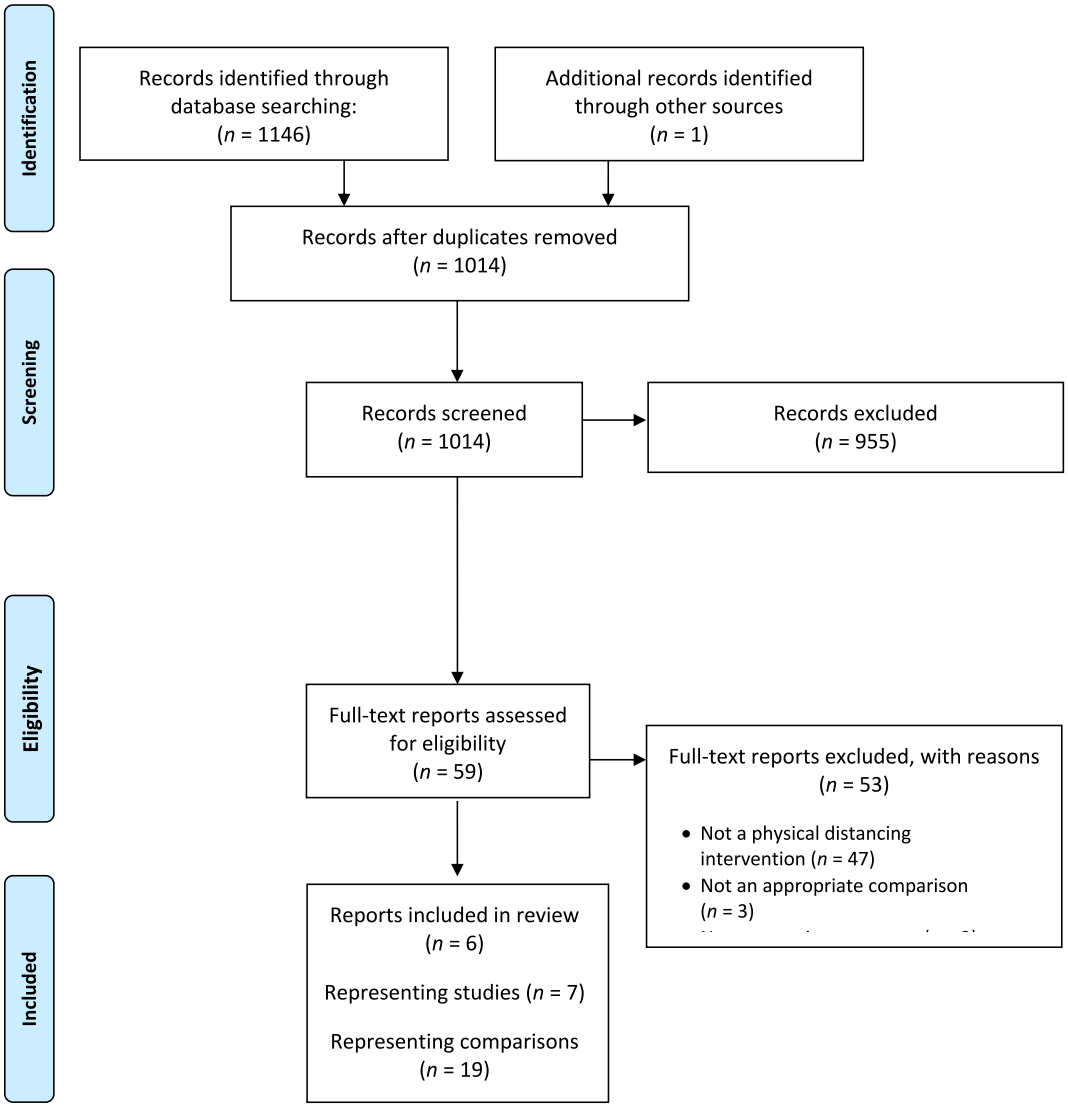

Fig. 1. Flow diagram of papers included in the review.

Table 1
Study characteristics.

Authors	Location and Sample	Conditions	Results
Bos et al. (2020)	Germany Online setting General population (N = 3616) Demographics not reported	Intentions/plans and support for government regulations were measured after receiving one of two message types or a no message control in this study 1. A consequentialist message (i.e., focused on consequences and included a photo of a credible source) 2. A Deontological message (i.e. focused on moral duty and included photo of credible source) 3. No message control	1. consequentialist message vs. no message control • No effects on intentions/plans to physically distance d = .06 • Significant difference in support for government regulations particularly in under 60-year-olds and women d = .10 2. deontological message vs. consequentialist message • No effects on intentions/plans to physically distance d = .04 • No difference in support for government regulations d = .03 3. deontological message vs. no message control • Significant difference in intentions/plans to physically distance d = .10 (This message is particularly effective for those under 60 and males) • Significant difference in support for government regulations particularly in under 60-year-olds and women d = .13
Blanken et al. (2020)	Netherlands Art Fair setting Graduates of Dutch art academies and others (N = 787) Demographics not reported	Behaviour (a count of distance violations was recorded electronically using a proximity device) was measured in four conditions that varied in walking directions and buzzers. 1. Unidirectional walking directions (with arrows on floor decals - one lane only) 2. Bidirectional walking directions (clockwise and anti-clockwise with arrows on floor decals) 3. Immediate buzzer (that immediately sounded when within 1.5m of another person from outside of your household. A demonstration of how it worked was included) 4. Delayed buzzer (sounded 2s after being within 1.5m of another person from outside of your household)	1. Unidirectional walking directions + immediate buzzer vs. immediate buzzer • The addition of unidirectional arrows indicating a one-way system decreased the number of distancing violations compared to immediate buzzer alone d = .40 2. Unidirectional walking directions vs. bidirectional walking directions • There were no differences between the one way and two-way systems d = −.13 3. Bidirectional walking directions + delayed buzzer vs. bidirectional walking directions • A delayed buzzer had no effect or had a negative effect. d = −.22 4. Unidirectional walking directions + immediate buzzer vs. unidirectional walking directions • Buzzers were effective in reducing distancing violations when the feedback from them was immediate and when visitors received a demonstration of the buzzer. d = .42
Chutiphimon et al. (2020)	Thailand University canteen setting University staff, students and others (N = 400) 83% were aged 19–64 years	Behaviour (from CCTV recordings were used to note success and failure to distance) was measured after exposure to three types of floor decal marker that were used to mark out 2m gaps (there were 5 markings (1–2 were side by side at the counter; 3–5 were queued adjacent) 1. Red arrow floor decal (red arrow between footprint stickers at 2m distance) 2. Coronavirus floor decal (an aggressive coronavirus with glowing eyes and “stop Covid-19” with cut out circle for feet) 3. Footprint floor decal (footprint stickers at 2m distance) - control	1. Red arrow floor decal vs. footprint floor decal • No difference in distancing at any marking between floor decals • Fewer failings in both groups at markings further away from counter Marking point 1: d = −.41 Marking point 2: d = .11 Marking point 3: d = .04 Marking point 4: d = −.08 Marking point 5: d = .85 Mean = .10 2. coronavirus floor decal vs. footprint floor decal • No difference in distancing at any marking between floor decals • Fewer failings in both groups at markings further away from counter Marking point 1: d = .29 Marking point 2: d = −.08 Marking point 3: d = −.01 Marking point 4: d = .52 Marking point 5: d = .40 Mean = .22 3. Text floor decal vs. footprint floor decal • Difference in marking point 1 (at the counter) between intervention and control but no differences at any other marking. • Fewer failings in both groups at markings further away from counter Marking point 1: d = .52 Marking point 2: d = −.21 Marking point 3: d = −.25 Marking point 4: d = −.48 Marking point 5: d = −.11 Mean = −11

(*continued on next page*)

Table 1 (*continued*)

Authors	Location and Sample	Conditions	Results
Hoeben et al. (2021)	Netherlands Outdoor public space setting General population (N = unknown) Demographics not reported	Behaviour was measured at four time points. CCTV recordings used to note failure of 1.5m distancing or when in groups of >3 people (not from your household). Cell phone data was also collected to measure change in time spent at non-residential places. 1. Pre-outbreak measures (Jan 2020–Feb 2020) 2. Outbreak but pre government recommendations (29 Feb to 12 Mar 2020) 3. Government recommendations (to keep 1.5m apart) (19 Mar 2020 to 21 Mar 2020) 4. Government recommendations (to keep 1.5m apart) and fines (for not complying with 1.5m distancing) (26 Mar to 2 May 2020)	Not possible to calculate d as did not count non-violations 1. Government recommendations vs. pre outbreak • Decline in failures to distance from 12 March (no explicit distancing rule) and continues to decline after 1.5m recommendation (after 15 March) with lowest number of 19 March (before explicit rules and announcement of fine). • 12–19 March there is a decline in number of people on street from CCTV data (compared to Jan–Feb 2020). Number of people on street positively correlated with number of violations. • Up to 12 March number of people in non-residential places was same as pre-COVID. 12–19 March there is sharp decline in time spent at non-residential locations 2. Government recommendations + fines vs. government recommendations pre fines • After explicit rule and fines for physical distancing there is a steady increase in violations (especially on weekends) from early April to early May. Increase in violations related to increase in number of new cases. • Number of people on street positively correlated with number of violations. Time spent at non-residential locations relatively low until 4 April when started to increase. Correlation between time spent at non-residential locations and distancing violations remains even after people on street controlled for.
Khoa et al. – study 2 (2021)	USA Online setting General population (N = 104) 71.2% female; mean age 42.18 years	Intentions, fear, and self-efficacy were measured after exposure to one of three message types 1. Gain-framed "promotion" message (Image of two figures standing apart and text "maintaining physical distance protects yourself from being infected with the coronavirus and secures your personal life") 2. Loss-framed "prevention" message (Image of two figures standing apart (with arrow) and text "failing to maintain physical distance risks yourself of being infected with the coronavirus and endangers your personal life") 3. Minimal message (Image of two figures standing apart with "please maintain physical distance") - control	1. Gain-framed message vs. minimal message • Intentions were not reported but assume no significant differences between control and gain-framed ("promotion"). Cannot calculate d 2. Loss-framed message vs. minimal message • Greater intentions to distance between loss-framed ("prevention") and control. Cannot calculate d 3. Loss-framed message vs. gain-framed message • Greater intentions to distance between loss-framed ("prevention") and gain-framed ("promotion"). Chronic prevention focus (i.e., a tendency to avoid losses) does not moderate this effect. Cannot calculate d • Loss-framed ("prevention") reported higher fear than gain-framed ("promotion"). Fear was shown as a mediator of the effect of the physical distancing intervention (comparing loss and gain framed) on intentions. Cannot calculate d • There was no difference loss-framed ("prevention") and gain-framed ("promotion") on self-efficacy and this was not a mediator d = .27
Khoa et al. - study 3 (2021)	USA Online setting General population (N = 124) 43.5% female; mean age 41.77 years	Intentions were measured after exposure to one of four message type 1. Loss-framed "prevention" message (Image of two figures standing apart (with arrow) and text "failing to maintain physical distance risks yourself of being infected with the coronavirus and endangers your personal life") 2. Gain-framed "promotion" message (Image of two figures standing apart (with arrow) and text "maintaining physical distance protects yourself from being infected with the coronavirus and secures your personal life") 3. Loss-framed message with anthropomorphic scary cartoon coronavirus between the figures 4. Gain-framed message with anthropomorphic scary cartoon coronavirus between the figures	1. Main effects of message type • Higher intentions in loss-framed ("prevention") than gain-framed ("promotion") conditions. Cannot calculate d 2. Main effects of anthropomorphic image • Higher intentions in anthropomorphic than non-anthropomorphic conditions. Cannot calculate d 3. Interaction between message type and anthropomorphic image • anthropomorphic image is absent loss-framed ("prevention") have greater intentions than gain-framed ("promotion") d = .59 • anthropomorphic image increased intentions in loss-framed ("prevention") compared to anthropomorphic gain-framed ("promotion") d = 1.76 • anthropomorphic image in loss-framed ("prevention") condition increased intentions compared to non-anthropomorphic loss-framed ("prevention") condition d = .70
Lunn et al. (2020)	Ireland Online setting	Perceived effectiveness and perceived memorability were measured after exposure to one of three posters	1.individual person poster vs. control poster

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Table 1 (*continued*)

Authors	Location and Sample	Conditions	Results
	General population (N = 500) 49% female; 33% < 40 years/31% 40–59 years/ 36% > 60 years	1. Individual person poster (4 panels, each with an image of people not maintaining social distance, with text-bubbles that foretold stories of chains of infection. Showed individuals who don't realize they have the virus, spreading it to an identifiable vulnerable person. Including counterfactuals "if they had sat further away she'd have been ok" and open-ended implications "he has asthma") 2. Transmission rate poster (4 panels, each with an image of people not maintaining social distance, with text-bubbles that foretold stories of chains of infection. Showed individuals unwittingly spreading the virus to multiple others. Including counterfactuals "Had they sat further apart those people would have been ok" and open-ended implications "will now give COVID-19 to her colleagues, they'll give it to their families") 3. Control poster (Featureless figurative cartoons in 4 panels depicting distancing in 4 social situations (i.e., walking in the street, sitting at a table, when shopping, on a football field))	• Control poster was significantly seen as more effective and memorable than intervention poster (calculated by number of people who selected maximum score as data highly skewed) $d = -.32$ effectiveness $d = -.37$ memorability 2. Transmission rate poster vs. control poster •No significant differences between the control poster and the transmission rate poster (calculated by number of people who selected maximum score as data highly skewed) $d = -.15$ effectiveness$d = -.23$ memorability 3. Transmission rate poster vs. individual person poster •No differences between the transmission rate poster and the individual person poster (calculated by number of people who selected maximum score as data highly skewed) $d = .17$ effectiveness$d = .14$ memorability

included a section on BCTs, the potential MoAs through which these operate, theoretical domains and intervention functions.

4. Results

The flow of articles into the review appears in Fig. 1 (Page et al., 2021). Potentially relevant articles ($N = 1146$) were identified from the database search and 1 article was obtained from other sources. Titles and abstracts ($N = 1014$) were screened for eligibility after removing 133 duplicates; articles that did not meet the inclusion criteria ($n = 956$) were excluded, leaving 59 articles for which full texts were obtained and read. A further 53 articles were excluded after the full text was examined; the principal reason for exclusion at this stage were that no physical distancing intervention occurred ($n = 47$). The remaining articles ($n = 6$) met the inclusion criteria for the review, reporting tests of the impact of physical distancing interventions on behavior or predictors of behavior.

4.1. Study characteristics

The 6 articles that met the inclusion criteria reported the effect of 14 interventions (and 3 other control interventions) and included over 5531 participants (One study, Hoeben et al., 2021, did not report the N due to the nature of the observational study design). The studies included randomized controlled trials ($n = 4344$; Bos et al., 2020; Khoa et al., 2021; Lunn et al., 2020); non-randomized trials ($n = 1187$; Blanken et al., 2020; Chutiphimon et al., 2020); and a natural experiment (n = unknown; Hoeben et al., 2021).

Studies were based in Europe (Bos et al., 2020; Blanken et al., 2020; Hoeben et al., 2021; Lunn et al., 2020), Asia (Chutiphimon et al., 2020); and North America (Khoa et al., 2021) (See Table S2 in Supplementary Materials for full study characteristics). Study samples were from the general population (Bos et al., 2020; Hoeben et al., 2021; Khoa et al., 2021; Lunn et al., 2020); university staff, students, graduates, and visitors to an art fair (Blanken et al., 2020; Chutiphimon et al., 2020) and data was collected between January 2020 (pre pandemic comparison) and August 2020 (see Table S3 in Supplementary Materials).

The interventions varied in delivery methods and BCTs used – (see Table 1 for a description of studies and see Table S2 in Supplementary Materials for a full description of studies including context, behaviour change techniques).

4.2. Risk of bias

The randomized controlled trials varied in risk of bias. All studies had a clear research question and the data was appropriate to answer the research question. Only one study (25%) included details of how randomization was managed (Bos et al., 2020); the others were unclear (due to the online nature of the studies, randomization was likely to have been undertaken by computer algorithm although this was not reported). Two studies (50%) reported randomization checks to evaluate if the groups were comparable at baseline; one of those studies found slight differences in age between conditions that was likely to be due to chance (Bos et al., 2020; this was controlled for in subsequent analysis) and the other found no differences between conditions (Lunn et al., 2020). All studies had complete outcome data (of at least 80% of those who had been randomized completed the study). All the studies (100%) had outcome assessments that were conducted without the involvement of the person delivering the intervention. All used self-report data; for 3 of the studies the participants were blinded to condition as each received some form of intervention; however, control participants in two of the comparisons in the Bos et al. study had participants who were potentially not blinded to condition as they were in a 'no message' control. All of the studies had participants who were exposed to the intervention; although only one (Bos et al., 2020) performed a treatment check to ensure the intervention was attended to.

For the non-randomized trials, one of the study samples (50%) was representative of the target population (i.e., Chutiphimon et al., 2020, targeted university canteen customers and their sample reflected this); the other study was not clear who their target population was but pointed out it was not representative of the general population (Blanken et al., 2020). For appropriate measurement, Chutiphimon et al. (2020) trained observers in a pilot study to improve reliability of their observations and Blanken et al. (2020) used a device that was accurate to within 10cm (Tanis et al., 2021). Regarding complete outcome data, both studies do not report drop-out data – although, with observational studies this criteria may not be applicable. Regarding confounding variables, both studies did not control for all possible confounds (e.g., Blanken et al. (2020) may have had people who stayed at the art fair beyond their allotted time slot so were in more than one condition; Chutiphimon et al. (2020) did not control for crowd size). Regarding the delivery of the intervention as intended, both studies delivered the interventions as intended; although, Blanken et al. (2020) adjusted their protocol to allow participants to test the proximity buzzers after an

initial session. There was a low non-response rate as all people in the area at the selected times were included in the study so there was no opportunity for "non-response".

For the quantitative descriptive study, the sampling strategy was relevant as the research question was to find the extent to which the general population complies with physical distancing directives in public places and their sample was people captured on CCTV in multiple public places over 10 weeks, which was collected on a weekday and a weekend day at a 5 min interval during a busy period (Hoeben et al., 2021). The sample was representative of their target population of people who used public places. The measurement was appropriate and had adhered to a codebook. The analysis was explained, justified and limitations were recognized.

See Table 2 for the breakdown of risk of bias for each study.

4.3. Main results

The results are broken down by the policy category that each intervention fits into (Michie et al., 2011). The policy categories included are: *legislation, environmental/social planning, regulation, and communication/marketing* (Michie et al., 2011).

4.4. Legislation

Legislation is "making or changing laws" (p. 7; Michie et al., 2011); one intervention measured the effect of legislation through government fines (Hoeben et al., 2021) to explore the effect on distancing behavior.

4.5. Government fines

Hoeben et al. (2021) measured distancing behavior in a natural experiment. They compared CCTV footage taken pre and post the government fines (after 23 March 2020) that were introduced to punish non-compliance of breaching a 1.5m physical distancing mandate and meeting in groups of 3 or more). After the government fines were introduced, there was a steady increase in distancing violations from early April 2020 to early May 2020 (especially on weekends) – this was correlated with an increased number of people on the street (as shown on the CCTV footage) and an increased number of people in non-residential locations (taken from cell phone data) (Hoeben et al., 2021). There is therefore no evidence that government fines influenced distancing behavior.

4.6. Environmental/social planning

Environmental or social planning is "designing and/or controlling the physical environment" (p. 7; Michie et al., 2011); two studies explored the effect of environmental changes using directional systems (Blanken et al., 2020) and distancing markers (Chutiphimon et al., 2020) to explore the effect on distancing behavior.

4.7. Directional systems

A non-randomized trial tested the implementation of one-way systems on distancing behavior (Blanken et al., 2020). One-way floor decal arrows were used to indicate walking directions at an art fair and behavior was measured using proximity sensors worn by visitors. One set of comparisons included comparing one-way arrows versus no arrows (both conditions also included a buzzer that sounded when within 1.5m proximity of another person). The addition of one-way arrows decreased the number of distancing violations ($d = 0.40$). However, a further comparison of one-way arrows versus bi-directional arrows (two lanes – clockwise and anti-clockwise) found that there was no difference between the two conditions with slightly fewer violations in the bi-directional arrow condition ($d = -0.13$).

4.8. Distancing markers

A four-day observational study of distancing behavior in a university canteen explored the effectiveness of floor decal stickers that marked out 2m distances (2 side by side at the canteen counter and 3 adjacent to the counter) (Chutiphimon et al., 2020). There were 4 different kinds of floor decal stickers: (1) a red arrow between footprint stickers at 2m distances to show the direction to queue; (2) an image of an aggressive red "scary" coronavirus with glowing eyes and "Stop COVID-19" printed under it with cut-outs for feet at 2m distances; (3) a written message between footprint settings of (e.g., "Physical distancing and Win COVID-19" [sic], "Please maintain a distance from other customers" and "Please queue here"); and (4), the footprint stickers alone (Chutiphimon et al., 2020). The red arrow ($d = 0.10$), the "scary" coronavirus ($d = 0.22$) or written message ($d = -0.11$) were not significantly more effective overall than the footprint stickers alone (Chutiphimon et al., 2020). The written message was significantly more effective than the footprint stickers alone at one of the marking points near the counter ($d = 0.52$) but not at the other (Chutiphimon et al., 2020). With all groups there were fewer violations of distancing at markings further away from the counter (Chutiphimon et al., 2020).

4.9. Regulation

Regulation is "establishing rules or principles of behavior or practice" (p. 7; Michie et al., 2011); two studies used this method through government recommendations (Hoeben et al., 2021) and proximity indicators (Blanken et al., 2020) to measure the effect on distancing behavior.

4.9.1. Government recommendations

One study, from the Netherlands, explored physical distancing prior to and post government distancing recommendations (Hoeben et al., 2021). This natural experiment used CCTV footage of open public spaces and compared footage from dates that were prior to government recommendations about physical distancing (29 February to 12 March 2020) and post government recommendations (after 15 March 2020). The behavior measured was a count of distancing violations. These started to decline from 12 March 2020 even though no explicit distancing recommendation was in place and continued to decline after the government recommendation on the 15 March 2020 until the 19 March 2020. There was no strong evidence that the explicit government recommendations influenced distancing behavior as this was already occurring prior to the government recommendation to physically distance (Hoeben et al., 2021).

4.9.2. Proximity indicators

A non-randomized trial tested the use of buzzers (i.e., a device that buzzed when within 1.5m of another person) on distancing behavior (Blanken et al., 2020). Participants in all conditions had their behavior monitored electronically using a proximity device. In some conditions, the proximity devices additionally included a buzzer that provided feedback when proximity was breached. There were 3 conditions: (1) the buzzer sounded immediately when within the 1.5m range (and users received a demonstration of how the buzzer worked); (2) the buzzer had a 2-s delay in buzzing after being within the 1.5m range; and (3), a no-buzzer control condition. The buzzer was effective in reducing distancing violations when the buzzer sounded immediately when within the 1.5m range ($d = 0.42$) compared to a condition without buzzers. The buzzers were ineffective when there was a 2-s delay in

buzzing after being within the 1.5m range ($d = -0.22$).

4.10. Communication/marketing

Communication and marketing is defined as "using print, electronic, telephonic or broadcast media" (p. 7; Michie et al., 2011). Three studies used communication and marketing through written messages (Bos et al., 2020), and posters (Khoa et al., 2021; Lunn et al., 2020). These studies measured intentions to distance (Bos et al., 2020; Khoa et al., 2021), support for government regulations (Bos et al., 2020), self-efficacy (Khoa et al., 2021), fear (Khoa et al., 2021), perceived effectiveness (Lunn et al., 2020) and memorability (Lunn et al., 2020).

4.10.1. Written messages

A large scale randomized controlled trial ($N = 3616$) explored the effect of three conditions (Bos et al., 2020): (1) a brief written message delivered online, from a credible source (i.e., medical professional), about the health consequences of not physically distancing, (2) a brief written message, from a credible source, focusing on the moral duty to physically distance and (3) a no message control. The health consequences message was not effective in increasing intentions to physically distance ($d = 0.06$) but did increase support for government regulations ($d = 0.10$) compared to a no message control (Bos et al., 2020) with a very small effect size. The moral duty message was effective in increasing intentions to physical distance ($d = 0.10$) and for support for government regulations ($d = 0.13$) compared to a no message control (Bos et al., 2020) with a very small effect size. However, there were no differences between the health consequences and the moral duty message on intentions and no data about the impact of the intervention on subsequent behavior.

4.10.2. Posters

Two randomized controlled experiments compared various interventions (Khoa et al., Studies 2 & 3, 2021): (1) a poster with an image of 2 featureless figure cartoons standing a distance apart with a 2-way arrow between that included a message focused on showing how the behavior steers away from negative outcomes (i.e., a loss-framed message - "Failing to maintain physical distance risks yourself of [sic] being infected with the coronavirus and endangers your personal life"), (2) the same picture with a message focused on positive outcomes (i.e., a gain-framed message - "Maintaining physical distance protects yourself from being infected with the coronavirus and secures your personal life"), (3) a control poster - the same picture with a message to "Please maintain physical distance", (4) the loss-framed poster with the addition of an anthropomorphic image of a coronavirus and (5) the gain-framed poster with the addition of an anthropomorphic image of a coronavirus.

The loss-framed poster was more effective at increasing intentions to physically distance than the control poster (Khoa et al. – study 2, 2021), and the gain-framed poster (Khoa et al. – study 2, 2021; Khoa et al., - study 3; $d = 0.59$). There were no differences in self-efficacy between the loss-framed and the gain-framed posters. The loss-framed poster also increased fear more than the gain-framed poster and fear mediated the effect of the intervention on intentions (Khoa et al. – study 2, 2021).

The addition of an anthropomorphic image of a coronavirus to the gain-framed and loss-framed message also resulted in increased intentions with a loss-framed message compared to the gain-framed message (Khoa et al., - study 3, 2021; $d = 1.76$). None of the studies measured impacts on behavior.

An online randomized experiment compared three posters (Lunn et al., 2020) on ratings of perceived effectiveness and memorability. One poster (that acted as the control) was an instructional poster that included four panels with images of two featureless figure cartoons at a 2m distance apart in four situations (i.e., walking in the street, sitting at a table, when shopping, on a football field). The second poster (referred to as the individual person poster) referred to transmission of the virus to an individual by showing four panels of groups of people not physically distancing and included comments referring to one person who "Has COVID-19 but doesn't know it yet" and the implied consequences of this "Has an undiagnosed heart condition. If they had sat further apart, she'd have been ok." The third poster (referred to as the transmission rate poster) was similar to the second poster but referred to transmission to others but not to an individual person; it showed four panels of groups of people not physically distancing with comments referring to a person who "Has COVID-19 but doesn't know it yet" and the implied consequences of this "Will now pass the virus onto 6 others. If they had sat further apart, she'd have been ok"). The featureless figure poster was perceived as more effective ($d = -0.32$) and memorable ($d = -0.37$) than the individual people transmission poster (Lunn et al., 2020) but not the transmission rate only poster ($d = -0.15$ for effectiveness; $d = -0.23$ for memorability); there were also no significant differences between the transmission rate and the individual person posters ($d = 0.17$ for effectiveness; $d = 0.14$ for memorability; Lunn et al., 2020). However, behavior was not measured and the perceived effectiveness and memorability of posters are not necessarily predictors of behavior change.

4.11. Behavior change techniques, mechanisms of action, and intervention functions

4.11.1. Behavior change techniques

For each intervention, we identified the BCTs that were included, the theoretical domains and potential MoAs for change, and the intervention functions that were the means to change behavior. We report below the effect of these BCTs (a summary is included in Table 3 and Tables S4–S6 in Supplementary Materials). However, it is important to note that the BCTs were not tested in isolation and may have interacted with each other.

Monitoring of behavior by others without feedback (2.1) was detrimental to behavior change when compared to the same electronic monitoring system but including *feedback on behavior (2.2)* using proximity buzzers (Blanken et al., 2020).

Feedback on behavior (2.2) was effective, although the unique effect of this was not tested (Blanken et al., 2020).

Information about health consequences (5.1) was effective when using a brief loss-framed message on a poster *demonstrating the behavior (6.1)* (Khoa et al., 2021) and when a moral duty poster was compared with a measurement only control (Bos et al., 2020). *Information about health consequences (5.1)* was ineffective when delivered via a message focused on avoiding consequences from a credible source (health consequences - Bos et al., 2020), a gain-framed message focused on gaining positive outcomes (Khoa et al., 2021), and posters showing transmission routes (Lunn et al., 2020). *Salience of consequences (5.2)* were effective when using a coronavirus image on a loss-framed poster that demonstrated the behavior (6.1) (Khoa et al., 2021) but not when they were used to separate 2m floor decals (Chutiphimon et al., 2020).

Demonstration of the behavior (6.1) worked with a brief loss-framed message to increase intentions (Khoa et al., 2021). *Demonstration of the behavior (6.1)* and *instructions to perform the behavior (4.1)* increased perceived effectiveness and memorability of the message (Lunn et al., 2020).

There were inconclusive results for *credible source (9.1)* as there was no difference between a health consequences message and a control but a moral duty message was effective in influencing intentions (Bos et al., 2020). Guidelines from the government, which may be regarded by some as a credible source, did not influence actual behavior (Hoeben et al., 2021).

Table 2
Methodological quality of studies.

Study	Screening		Randomized Controlled Trials		Non Randomized Trials		Quantitative Descriptive Study											
	Clear Research Question	Data addresses Research Question		Randomization appropriately performed	Comparable groups at baseline	Complete outcome data (≥ 80%)	Outcome assessor blinded	Participants adhere to assigned Intervention	Participants representative	Appropriate measurement	Complete outcome data (≥ 80%)	Confounders accounted for	Intervention delivered as intended	Relevant sampling strategy	Representative sample	Appropriate measurement	Low non response bias	Appropriate analysis
Bos et al. (2020)	Yes	Yes		Yes	Yes*	Yes	Outcome assessor blinded**	Yes										
Khoa et al. (2021) – study 2	Yes	Yes		Cannot tell	Cannot tell	Yes	Yes	Yes										
Khoa et al. (2021) – study 3	Yes	Yes		Cannot tell	Cannot tell	Yes	Yes	Yes										
Lunn et al. (2020)	Yes	Yes		Cannot tell	Yes	Yes	Yes	Yes										
Blanken et al. (2020)	Yes	Yes							Cannot Tell***	Yes	Cannot tell	No	Yes+					
Chutiphimon et al. (2020)	Yes	Yes							Yes	Yes	Cannot tell	No	Yes					
Hoeben et al. (2021)	Yes	Yes												Yes	Yes	Yes	Yes	Yes

Notes.
*there was a slight but significant difference in age, that was likely due to chance, and that was controlled for in subsequent analysis.
**for two of the three comparisons the participants were likely not blinded to condition as they were in a no message control and the measure was self-report.
***target population was not mentioned, the sample was recruited from an art fair so was not representative of the general population.
+intervention was delivered as intended but after an initial session where participants tested their proximity buzzers during the study time they changed the protocol to allow give them a demonstration of this prior to entering the study.

Comparative imagining of future outcomes (9.3) was not effective in changing perceived effectiveness and memorability (Lunn et al., 2020). *Future punishment (10.11)* with a government fine was not effective in changing behavior (Hoeben et al., 2021).

Restructuring the physical environment (12.1) with direction walking systems was effective at increasing physical distancing (Blanken et al., 2020).

Framing/reframing (13.2) as a moral duty was effective at changing intentions when compared to a control but not to a health consequences message (Bos et al., 2020).

Two BCTs were identified that were used in several interventions but were only compared with alternative interventions that also included that BCT: These were *prompts and cues (7.1)* (Blanken et al., 2020; Chutiphimon et al., 2020; Khoa et al., 2021; Lunn et al., 2020) and *habit formation (8.3)* (Chutiphimon et al., 2020). This means that the effect of these two BCTs was not assessed in these studies.

4.12. Mechanisms of actions

The MoAs that are potentially influenced by the BCTs are summarised in Table S4. The potential MoAs that were most common were *intentions* and *behavioral cueing*. *Intentions* were potentially influenced (or even actually influenced as this was measured in some studies) by BCTs such as *information about health consequences (5.1), salience of health consequences (5.2), demonstration of behavior (6.1),* and *framing/reframing (13.2)*.

Behavioral cueing was potentially influenced by BCTs such as *prompts and cues (7.1), habit formation (8.3), restructuring the physical environment (12.1),* and *adding objects to the environment (12.5)*.

Other common potentially influenced MoAs were *beliefs about consequences, attitude towards the behavior*, and *environmental context and resources*. *Beliefs about consequences* were potentially influenced by BCTs such as *information about health consequences (5.1), salience of health consequences (5.2),* and *comparative imagining of future outcomes (9.3)*.

Attitude towards the behavior were potentially influenced by BCTs such as *information about health consequences (5.1), credible source (9.1)* and *framing/reframing (13.2)*.

Environmental context and resources were potentially influenced by the BCTs that were delivered through *prompts and cues* (7.1), *restructuring the physical environment* (12.1) and *adding objects to the environment* (12.5).

Fewer interventions used BCTs that were related to other potential MoAs (i.e., *knowledge, beliefs about capabilities, perceived susceptibility/vulnerability, physical skills, social learning/imitation, memory, attention and decision-making processes, feedback processes, motivation*, and *general attitudes and beliefs*). These MoAs, related BCTs and their effectiveness are cross-referenced in Table S4.

The interventions of directional walking systems and proximity buzzers that used *restructuring the physical environment (12.1)* and/or *adding objects to the environment (12.5)* that are related to the MoAs of *environmental context and resources, behavioral cueing, feedback processes* and *motivation* were particularly effective at increasing distancing behavior (Blanken et al., 2020).

4.13. Theoretical domains

Six theoretical domains (that identify what needs to change in order for behavior change to occur) were related to the BCTs. The most common domain was *environmental context and resources* that was related to 3 BCTs: *Restructuring the physical environment (12.1), objects added to the environment (12.5)* and *prompts and cues (7.1)*. Changing the *environmental context and resources* seemed particularly effective through introducing directional systems and proximity buzzers (without a delay; Blanken et al., 2020).

Knowledge was related to *feedback on behavior (2.2)* and *information about health consequences (5.1)*. Beliefs about consequences was related to the BCTs of *salience of consequences (5.2)* and *comparative imagining of future outcomes (9.3)*.

Physical skills and *social influence* were related to one BCT each. Physical skills were related to *habit formation (8.3)*. Social influence was related to *demonstration of behavior (6.1)*. These theoretical domains, BCTs, and their effectiveness are cross referenced in Table S5.

4.14. Intervention functions

There were 8 intervention functions that the BCTs were potentially related to that were the potential means to change behavior. These were *persuasion, enablement, training, education, coercion, environmental restructuring, incentivisation,* and *modelling*.

The most commonly used intervention function was *persuasion* related to 5 BCTs (2.2, 5.1, 5.2, 9.1, 13.2). *Training* (2.2, 4.1, 6.1, 8.3) and *enablement* (9.3, 12.1, 12.5, 13.2) were related to 4 BCTs. *Coercion* (2.1, 2.2, 10.11), *education* (2.2, 5.1, 7.1), and *environmental restructuring* (7.1, 12.1, 12.5) were related to 3 BCTs each. *Incentivisation* (2.1, 2.2) and *modelling* (6.1) were related to 2 and 1 BCT, respectively. *Environmental restructuring* seemed the most effective means of changing distancing behavior as directional systems and proximity buzzers were effective (Blanken et al., 2020). The intervention functions, BCTs and their effectiveness are cross referenced in Table S6.

5. Discussion

The current systematic review identified six articles reporting the effects of 14 interventions (in 7 studies and 19 comparisons). This review has identified which intervention components have been tested and the strength of this evidence. This focused mainly on effective policy categories (i.e., how to deliver an intervention function), behavior change techniques (i.e., how to change the behavior), the delivery mode (i.e., how to deliver the BCTs), and the potential mechanisms of action (i.e., how the BCTs work). It provides important guidance for policymakers on possible interventions to promote this key health protective behavior (Hart et al., 2021; Chater et al., 2020, 2021).

5.1. Policy categories

The review assessed evidence for interventions that were in four of the policy categories: *legislation, environmental and social planning, regulation* and *communications and marketing*. *Legislation* was shown (through government fines; Hoeben et al., 2021) to be an ineffective policy for encouraging physical distancing. Although the other three policy categories have the potential to produce change there is mixed evidence of effectiveness that depends upon the specific intervention type. *Environmental and social planning* policies changed physical distancing behavior when directional systems were used (Blanken et al., 2020) but there was no clear evidence that footprint decals were effective (Chutiphimon et al., 2020). *Regulation* changed behavior when proximity indicators, without a delay, were used (Blanken et al., 2020) but not when delivered as government recommendations (Hoeben et al., 2021). *Communications and marketing* was effective when delivered via some posters (Khoa et al., 2021) but not for other posters (Lunn et al., 2020) and written messages (Bos et al., 2020). The policy categories of *guidelines, fiscal measures*, and *service provision* were not used as a means to change behavior in the included interventions. Although not tested in the included studies, guidelines that detail how to manage physical distancing practices within public areas may be particularly useful in encouraging distancing behavior.

5.2. Behavior change techniques

The review found support for several BCTs involved in physical distancing behavior. These included BCTs that were identified in survey studies including: *Providing feedback on the behavior (2.2)* (e.g., via

Table 3
Behavior change techniques, their delivery, and effectiveness.

Behavior change technique	Delivery and effectiveness
2.1 Monitoring of behavior by others without feedback	**Distance monitoring without a buzzer** *(Blanken et al., 2020)* Ineffective – the no buzzer control condition (where behavior was monitored with a proximity device without feedback) coupled with unidirectional walking directions only was less effective than the unidirectional walking directions with a buzzer Other BCTs: 7.1; 12.1
2.2 Feedback on behavior	**Proximity Buzzer** *(Blanken et al., 2020)* Effective – buzzer increased behavior when feedback is immediate (2 s delay ineffective) when coupled with physical restructuring Other BCTs: 7.1; 12.1; 12.5
4.1 Instruction on how to perform the behavior	**Poster demonstrating behavior** *(Lunn et al., 2020)* Inconclusive - Poster demonstrating behavior was significantly seen as more effective and memorable than other posters but did not measure intentions/behavior Other BCTs: 6.1; 7.1; 9.1 **Health consequences message** *(Bos et al., 2020)* Ineffective - no difference in intentions between this and a measurement only control or moral duty message Other BCTs: 9.1 **Moral duty message** *(Bos et al., 2020)* Inconclusive - message focusing on moral duty influenced intentions compared to message only control but no difference compared to health consequences message. Other BCTs: 9.1; 13.2
5.1 Information about Health Consequences	**Gain-framed "promotion" poster** † *(Khoa et al., 2021)* Ineffective - no difference between Gain-framed "promotion" and control poster on intentions Other BCTs: 6.1; 7.1 **Loss-framed "prevention" poster** *(Khoa et al., 2021)* Effective – increased intention when compared to Gain-framed "promotion" focused poster (2 studies) and control (1 study) Other BCTs: 6.1; 7.1 **Poster with consequences to individual people or about transmission rate** *(Lunn et al., 2020)* Inconclusive - individual person and transmission rate posters not effective in increasing effectiveness and memorability (and did not measure intentions or behavior) Other BCTs: 7.1; 9.1; 9.3
5.2 Salience of Consequences	**Floor decal markers with scary coronavirus** *(Chutiphimon et al., 2020)* Inconclusive – floor decal 2m markers with scary coronavirus don't increase behavior when compared to other 2m floor decal markers Other BCTs: 7.1; 8.3 **Loss-framed "prevention" poster with scary coronavirus** *(Khoa et al., 2021)* Effective – Loss-framed "prevention" focused posters were effective in increasing intention when compared the same posters w/o the scary coronavirus and Gain-framed "promotion" posters Other BCTs: 5.1; 6.1; 7.1
6.1 demonstration of behavior	**Gain-framed "promotion" poster** *(Khoa et al., 2021)* Ineffective - no difference between Gain-framed "promotion" and control poster on intentions Other BCTs: 5.1; 7.1 **Loss-framed "prevention" poster** *(Khoa et al., 2021)* Effective – increased intention when compared to Gain-framed "promotion" focused poster (2 studies) and control (1 study) Other BCTs: 5.1; 7.1 **Poster demonstrating behavior** *(Lunn et al., 2020)* Inconclusive - Poster demonstrating behavior was significantly seen as more effective and memorable than other posters but did not measure intentions/behavior Other BCTs: 4.1; 7.1; 9.1
7.1 Prompts *and* cues	No studies compared a condition with prompts and cues and one without any prompts and cues.
8.3 Habit formation	No studies compared conditions with habit formation strategies and one without habit formation strategies.
9.1 Credible source	**Health consequences/moral duty message** *(Bos et al., 2020)* Inconclusive - no difference between a control and a health consequences message from a credible source but difference with a moral duty message from a credible source Other BCTs: 5.1; 13.2 **Government Guidelines** *(Hoeben et al., 2021)* Inconclusive – behavior occurred before explicit government recommendations. May require other measures in place (e.g., stay at home orders) to facilitate change Other BCTs: N/A
9.3 Comparative imagining of future outcomes	**Poster with consequences to individual people or about transmission rate** *(Lunn et al., 2020)* Inconclusive - individual person and transmission rate posters not effective in increasing effectiveness and memorability (and did not measure intentions or behavior) Other BCTs:5.1; 7.1; 9.1
10.11 Future punishment	**Government Fines** *(Hoeben et al., 2021)* Ineffective – no evidence that fines influenced behavior Other BCTs: 9.1
12.1 Restructuring physical environment	**Directional walking system** *(Blanken et al., 2020)* Effective - one-way walking system increased behavior but no difference with bi-directional system Other BCTs: 2.2; 7.1
12.5 Adding objects to environment	**Proximity Buzzer** *(Blanken et al., 2020)* Effective – buzzer increased behavior when feedback is immediate (2 s delay ineffective) when coupled with physical restructuring Other BCTs: 2.2; 7.1; 12.1
13.2 Framing/reframing	**Moral duty message** *(Bos et al., 2020)* Inconclusive - message focusing on moral duty influenced intentions compared to message only control, but no difference compared to health consequences message. Other BCTs: 5.1; 9.1

proximity buzzers; Blanken et al., 2020); *information about health consequences (5.1)* (e.g., via posters with loss-framed messages; Khoa et al., 2021); and *restructuring the physical environment (12.1)* (e.g., via directional systems; Blanken et al., 2020).

Two techniques that may have been effective and were highlighted by previous survey studies; yet, these were not compared to a condition without those techniques. *Prompts and cues (7.1)* and *habit formation (8.3)* could be particularly effective enablers for physical distancing in distracting situations, as people would be reminded or have formed the habit.

Two other BCTs highlighted by survey studies had inconclusive evidence, (*framing/reframing (13.2),* Bos et al., 2020) or were not tested (*information about others' approval (6.3))*.

Other BCTs that were not mentioned in the literature and had some supportive evidence for changing intentions or behavior were *salience of consequences (5.2)* such as delivered via posters with loss-framed messages, with an image of a coronavirus standing between two figures (Khoa et al., 2021); *demonstration of the behavior (6.1)* such as delivered via posters with loss-framed messages (Khoa et al., 2021); and *adding objects to the environment (12.5)* through proximity buzzers (Blanken et al., 2020).

The review also identified BCTs that were ineffective. There was no support for using the BCT of *future punishment (10.11)* as government fines (Hoeben et al., 2021) were ineffective; this is supported by recent reviews suggesting that punitive approaches to public health are often ineffective or counterproductive (Independent SAGE, 2021; Mills et al., 2021).

There are other BCTs that were not tested but are potentially useful in changing distancing behavior. These are listed in the future research section. It is also worth noting that the included BCTs were not tested in isolation so their effectiveness may be due to their interaction with other BCTs in that intervention.

5.3. Mechanisms of action

Several MoAs were related to BCTs that were tested in the interventions included in this review. The most effective BCTs were related to *environmental context and resources, behavioral cueing, feedback processes,* and *motivation* but these were related to two interventions of directional walking systems and proximity buzzers (Blanken et al., 2020).

BCTs that were related to other potential MoAs had inconclusive results. However, interventions that used loss-framed prevention posters (Khoa et al., 2021) were effective at changing intentions that are also related to the MoAs: *attitudes towards the behavior, beliefs about consequences, knowledge, perceived susceptibility/vulnerability* and *social learning and imitation*. Prospect theory (Kahneman and Tversky, 1979) could explain why the loss-framed posters were successful as it suggests that when trying to change behaviors linked to health risk (e.g., physical distancing), loss frames (e.g., making negative consequences of not doing behavior salient) are more effective than gain frames (e.g., making the benefits of doing the behavior salient) as we are motivated to reduce the loss (see Abhyankar, O'Connor and Lawton, 2008).

5.4. Theoretical domains

The review found that BCTs from six of the fourteen theoretical domains were used. Changing the *environmental context and resources* seemed particularly effective with mixed evidence for BCTs that can influence *knowledge, beliefs about consequences,* and *social influence.* A theoretical domain that could be particularly relevant to encouraging physical distancing behavior is *cognitive and interpersonal skills*, as distancing is influenced by the behavior of other people; therefore having the skills to enable negotiation of space would be valuable.

5.5. Intervention functions

The review identified that eight of the nine intervention functions were related to the BCTs used in physical distancing interventions: *education, persuasion, modelling, environmental restructuring, enablement, training, incentivisation*, and *coercion*. *Restriction* (using rules to increase distancing by reducing the opportunity to engage in opposing behaviors; Michie et al., 2014) was not used. Application of this intervention function could be through managing crowds e.g., restricting the number of people in shared spaces rather than encouraging distancing as per the included interventions. *Environmental restructuring* was particularly effective as a means to change behavior (Blanken et al., 2020).

5.6. Other considerations

Physical distancing is influenced by the context in which it is performed such as restrictions on the opportunity to distance, distractions, and beliefs (e.g., around risk and trust). For example, distancing is affected by the number of other people in the vicinity (Hoeben et al., 2021; Liebst et al., 2020); stay at home orders facilitated distancing in Hoeben et al.'s study as there were fewer people in public spaces, which consequently made physical distancing easier. Distraction may also affect the ability to distance; for example, distancing behavior decreased when ordering food at the counter (Chutiphimon et al., 2020). Beliefs such as risk can affect distancing behavior. For example, those who lived in low risk areas had decreased physical distancing in an avatar study (Cartaud et al., 2020). There is mixed evidence that when risk is perceived to be lower, through wearing face-coverings, distancing behavior may change. An avatar study found that when avatars wore masks, people indicated they would stand closer (Cartaud et al., 2020; Luckman et al., 2020); however, 1.5m distancing was not related to mask wearing in a CCTV observational study (Liebst et al., 2020). Beliefs such as trust are also related to distancing behavior: Higher levels of trust in science and politics increased adoption of behaviors such as physical distancing (Dohle et al., 2020). Therefore, these contextual factors should be considered when designing physical distancing interventions.

5.7. Areas for future research

This review identified several limitations in the extant literature, which could be addressed in future research. First, measures in many studies conflated physical distancing when co-located (e.g., keep 1–2m apart; avoid hugging, kissing, hand shaking) with crowd avoidance (e.g., avoid crowded places, work from home, limit time spent away from home) – these studies were thus excluded from our review. Second, studies did not always report intentions or behavior; for example, Lunn et al. (2020) reported perceived effectiveness and memorability of the intervention posters but not intentions to distance or actual behavior. Although measuring these variables is useful when deciding between different posters addressing the same MoA and using the same BCTs it is less useful at early stages of research when identifying effective MoAs and BCTs is needed. An agreed core outcome set could be used to improve reporting standards (Shorter et al., 2019; Williamson et al., 2017). Third, as can be seen in Table S4 only fourteen out of twenty-six MoAs were coded as included in the interventions in this review and only fourteen out of ninety-three behavior change techniques were coded by this review's authors (moreover, none of the studies identified behavior change techniques using a taxonomy). Additionally, these have not always focused on MoAs that have been identified as potentially important, e.g., *behavioral regulation* was identified as an important target but was not tested in the included interventions (Hagger et al., 2020). Fourth, the interventions did not always compare interventions that differed in BCTs – for example, Chutiphimon et al. (2020) compared two interventions that both used *prompts and cues (7.1)*. Although this is useful when deciding the best way to deliver BCTs we know are

effective, it is less useful when we need to identify effective BCTs. *Behavioral regulation, perceived susceptibility/vulnerability*, and *social norms* were not addressed in the interventions included in this review. Fifth, the samples in the studies were largely unrepresentative of the general population (i.e., the sampling strategies were convenience sampling rather than aiming for a representative sample; however, two of the three studies assessed for this in the MMAT were representative of their target population) although the review itself included studies from several countries over three continents. Sixth, except for one study, the data were collected in *W*estern, *E*ducated, *I*ndustrialised, *R*ich and *D*emocratic countries (WEIRD – Henrich et al., 2010) so these results may not generalise to other contexts.

Further research into interventions to promote physical distancing behavior is needed. This review has identified which intervention components are promising, which are inconclusive, and which have not been tested. These intervention components are constructs that need to change (theoretical domains), the means to change the behavior (policy categories, intervention functions), strategies to change behavior (the BCTs), how to deliver the interventions and the mechanisms through which BCTs work (the MoAs). Future interventions could systematically test these intervention components. For example, *social comparison (6.2)* and *information about others' approval (6.3)* could be effective in changing *social norms* around physical distancing as social influences were promising domains identified in survey studies. BCTs such as *problem solving (1.2)* (e.g., finding solutions to address situations when distancing is difficult), *instructions on how to perform the behavior (4.1), demonstration of the behavior (6.1),* and *behavioral rehearsal (8.1)* could be effective in increasing *beliefs about capability*. Those BCTs could also be coupled with *information about health consequences (5.1)* as there is evidence that behavior is more likely when both perceptions of risk and self-efficacy are influenced by an intervention (Sheeran et al., 2014). The BCTs *information about social and environmental consequences (5.2)*, *anticipated regret (5.5)*, and *information about emotional consequences (5.6)* could influence *beliefs about consequences*; *goal setting (outcome) (1.1),* and *incentive (outcome) (10.8)* (e.g., information about the positive consequences of distancing on allowing opening up of restrictions) could influence *intentions* and *motivation*.

Studies that explore the barriers and facilitators of physical distancing are also required to ensure the interventions are optimised; for example, a barrier may be that physical distancing involves the co-operation of others so an intervention component that focuses on being able to communicate your distancing needs with others may be necessary.

5.8. Limitations of the review

We have identified three limitations of this review. First, there was only one high quality study (Hoeben et al., 2021 had a low risk of bias on all elements) in the review; although a higher risk of bias in the other studies was most often due to a lack of information rather than certainty of a high risk of bias. Second, we were not able to meta-analyse the data due to the small number of effect sizes for each outcome and problems with the independence of these effect sizes. Finally, the small number of studies and the unrepresentative samples meant we were unable to explore for whom the interventions best worked.

6. Conclusions

This review is the first review to summarise the state of the literature regarding physical distancing interventions. Although the review contains only a small number of studies, there is a need to evaluate emerging evidence to promote physical distancing during the ongoing COVID-19 pandemic. Research on physical distancing is still important even though some governments have relaxed restrictions to do this with the COVID-19 pandemic as some members of the public still wish to physically distance to keep themselves safe (Drury et al., 2021b); although these people may be motivated to physically distance, interventions may still be necessary to increase capabilities and opportunities. Furthermore, physical distancing may be necessary in the future as restrictions may be reimplemented with new strains of COVID-19 or for future pandemics. The review has extended our knowledge to show that physical distancing intentions and behavior can be increased but the size of the effect cannot be determined. Although there are BCTs that show influences on intentions and behavior, these are based on only a few studies so strong conclusions cannot be drawn. However, this review has provided recommendations for interventions to be tested in future research and has been used to develop recommendations (Hart et al., 2021) as a starting point for public health campaigns.

Pre-registration

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Declaration of competing interest

AK and JD participate in the UK's Scientific Advisory Group for Emergencies sub-groups SPI-B but are writing in a personal capacity.

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Appendix A. Supplementary data

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