5-13-2022

Nudging for Hand Hygiene: A Systematic Review and Meta-Analysis

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By

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22 APRIL 2022

ABSTRACT

INTRODUCTION: Despite its importance and having few significant technological barriers, hand hygiene continues to pose a serious problem in public health. In addition to the highly public impact of hand hygiene promotion accompanying the COVID-19 pandemic, inadequate compliance with recommended hand- washing and -sanitizing procedures contributes substantially to healthcare associated infections, food-borne illness and seasonal flu transmission, school- and workplace-based outbreaks, and other arenas of preventable disease. "Nudges" – simple, inexpensive cues or selection-environment features that are designed with cognitive biases in mind – are used frequently to promote compliance in a variety of health-related activities, including hand hygiene compliance.

AIM: To systematically review the literature discussing the efficacy of nudging in promoting hand hygiene, and to statistically summarize the results of those studies.

METHODS: Consistent with PRISMA and Cochrane guidelines for completing a systematic review and meta-analysis (SRMA), this study performs a planned and detailed review of literature through multiple appropriate databases and external resources, selects studies based upon predetermined inclusion and exclusion criteria, sequentially screens titles, abstracts, and full-texts for relevance and usability, extracts data systematically, and summarizes statistical results and effect sizes. Technological assistance is used to promote thoroughness and evaluative integrity. Specifically, Zotero is used in the selection and screening of studies, and R, R Markdown, and the R packages *metafor*[1] and *clubSandwich*[2] are used for conducting a meta-analysis using a correlated and hierarchical effects model.[3]

RESULTS: 14 studies contributing 34 effect sizes were analyzed using a multivariate random effects model with Robust Variance Estimation. The mean log odds ratio (LOR) was 1.416, with a mean odds ratio and 95% confidence interval of 4.12 [2.295 – 7.4] for hand hygiene within nudge-conditions compared to controls.

DISCUSSION: Nudges significantly increase hand hygiene compliance in a variety of populations and socio-cultural contexts, though publication bias may exaggerate their efficacy

APPROVAL PAGE

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Acknowledgements

I would like to thank Dr. Matt Hayat for serving on the panel for this thesis and its defense.

I would like to thank Dr. Heather Bradley for the same, as well as for many additional things. Most notably, I would like to thank her for talking me into coming to Georgia State for my MPH and for taking a chance on me as a GRA. In providing me a diverse array of interesting and important projects to work on, I was not only able to contribute to worthy causes and gain professional experience, but also to extend my network of peers and colleagues, and to learn an array of analytical tools that I otherwise would not have been exposed to. Likewise, the techniques I learned in her Epidemiological Methods II course for preparing, analyzing, and present health-related data continue to be the first resources I reach for whenever I begin – or get stuck in—a new project. In the interest of conserving space, I will oblige myself to not further enumerate my debts, but not before also noting my gratitude for her recommendations and advisement vis-à-vis further graduate studies.

Most of all, I would like to thank Dr. Terri Pigott. It is not hyperbole to say that she changed my life: her course in biostatistics was what ignited my passion for statistical research, gave me the confidence to pursue it and change tracks, and assured me that I would have a resource for encouragement, advisement, and support throughout the process of my degree program. Having taken (and taught) multiple mathematics and statistics courses over my life, I am a stranger to neither the catholicity nor the extremity of ways in which mathematics instruction can be utterly botched, and I am deeply aware of how significantly those experiences can shape a learner's perception of the field. It is all-too-common to leave a mathematics course feeling alienation, frustration, intimidation, and stress, and a rare gift to leave ebullient and impassioned. Dr. Pigott gave me that gift.

As if that weren't sufficient, she went on to teach two equally superb courses, to provide me with a smorgasbord of informative resources, and to not only serve on my thesis panel, but to take me up as a pupil, advising me on its completion. Her recommendations and advocacy on my behalf mean the world to me, and my time at GSU would have been completely different were it not for her.

Finally, I would like to thank my wife, Veronica, for being my inspiration and my stabilizing guide. Without her willingness and support, I would not have had the means – financial, temporal, or emotional – to complete this program and pivot in my career. Every guy thinks he married the best girl in the world, but in my case it's actually true. She is the most generous, patient, and encouraging person I have ever met, and it is a privilege to be her partner.

Author's Statement

In terms of form, this thesis borrows significantly from the Georgia State University's School of Public Health Master of Public Health's *Thesis Handbook* and *Initial Pages for Thesis Final Document*[4] guidelines (for reasons of requirement), the *PRISMA 2020 Checklist*[5] (industry standard guidelines for comprehensive and reliable SRMA) and the guidelines provided by Cochrane[6], as well as the paper *Systematic Review and Meta-Analysis of the Effectiveness of Nudging to Increase Fruit and Vegetable Choice* by Broers et. al.[7] (a peer-reviewed SRMA published in the *European Journal of Public Health* that served as an informal model for performing an SRMA at the nexus of microeconomics and public health). All equations and mathematical notation were composed using the LaTeX extension in Microsoft Word[8]. Additionally, this review was completed concurrently with PHPH 8890: Special Topics in Biostatistics – Systematic Review and Meta-Analysis, taught by Dr. Terri Pigott, and directly or indirectly reflects the influence of her instruction and the associated materials she provided.

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Chapter 1: Introduction

Background

In the year 1900, the rate of mortality for children under 5 in the United States was approximately 257 per 100,000 births[9]. Consistent with that staggering figure, the leading causes of death excluding child mortality in 1920 included influenza/pneumonia (1st, with 202/100,000 deaths: ~12%), tuberculosis (2nd, with 194/100,000 deaths: ~11%), gastrointestinal infections/diarrhea (3rd, with 143/100,000 deaths, ~8.5%), and diphtheria (10th, with 40/100,000: ~3%.)[10]. While cancer, heart disease, and stroke were all in the top 10, they cumulatively were responsible for ~18% of deaths, while the aforementioned infections constituted more than 1 in 3 at ~35% of all causes of mortality.[6]

By 2010, mortality from *all causes* was down 54%[11]. Child mortality was down by 250 to only 7 deaths per 100,000[12]. Influenza/Pneumonia was around 16/100,000 (~2%)[7]. Diphtheria was approximated to have a prevalence of less than 1 – 1 *case*, not percent—per year[13]. Likewise, tuberculosis shifted from 194/100,000 deaths to a mere 2.4/100,000 cases[14]. No other infectious disease appeared in the top 10 leading causes, and had child mortality been listed, it would have failed also to reach the top 10 by a considerable margin. The scientific and technological progress made in the key domains of vaccination, gynecology, and water and environmental sanitation are indisputably to thank for these shifts[15].

On the other hand, cancer and heart diseases have roughly tripled in terms of their percentage representations – together they caused nearly 1.2 million deaths (~ 50%) in 2010[7]. Additionally, new players like diabetes, non-infectious airway diseases, and suicide have filled the spots vacated by the infections of 1910. Strokes, neurodegenerative disease, and nephropathies have stubbornly held their positions, and accidents – though declining—have also stayed in the running[7]. Meanwhile, some oddballs have emerged into public consciousness: Healthcare-associated infections (HCAIs) caused nearly 100,000 deaths in 2018[16]; antibiotic-resistant infections lead to somewhere between 30,000 – 50,000 deaths annually[17]; and, of course, the COVID-19 pandemic scarcely requires mentioning.

In some part, these figures are paradoxical: as the deleteriousness of infectious disease has declined, the population lives longer, leading to higher rates of death from age-related illness (e.g., cancer, Alzheimer's disease, and, to a lesser extent, heart disease and stroke). The same innovations that permitted the development of technologies for prevention, diagnosis, and treatment also permitted high-speed travel and interstate commerce, exacerbating the threat of international pandemic-emergence. The engines powering ambulances also power the vehicles of drunk drivers. The hospitals that safely deliver so many infants every year and the antibiotics that have driven away gastrointestinal disease become vectors for the transmission of artificially enhanced pathogens.

Still, it is hard not to notice something else unique about the present state: how distinctly unmysterious, solvable, and behavioral the principal ailments are. Without digressing into metrics of Potentially Preventable Deaths[18], Disability-Adjusted Life-Years[19], Years of Potential Life Lost[20], and so on, it is incontrovertible that the etiologies, biomechanics, and risk factors associated with virtually all of the leading causes of death in the United States and elsewhere in the developed world are well-understood and widely known[21]. In contrast to a past characterized by Aristotelian theories of disease and limited microscopy, where sickness and death were, in many cases, black boxes (misfortune, bad humors, divine retribution, and so on), today there are theories of most maladies that fully or partially satisfy the Bradford-Hill criteria and related diagnostic frameworks[22]. Mokdad, et al, estimated in 2005 that the "Actual causes of death" in the United States accounted for nearly 45% of deaths—causes like tobacco, poor diet, sedentary lifestyle, alcohol consumption, motor vehicle crashes, drug use, sexual behaviors, and driving accidents[23].

Relatedly, as the comprehensibility of these sicknesses increases, so also does their tractability. Since this paper is not intended to serve as review of estimates, it will simply be left to the reader's imagination to consider the costs and benefits of (in no particular order, and globally as well): whole foods plant-based diets, widespread compliance with vaccination, medication, and sanitation, sex education and appropriate use of condoms, annual checkups, needle exchanges, mosquito nets, insect repellant, nicotine patches, bike paths, walking trails, whole food school lunches, free addiction counseling, naloxone, sugar-level restrictions, and so on.

However, consideration of these inexpensive, widely available, and highly effective options, almost begs for discussion of the third component above. Namely, the discussion of why, given the existence of those things, they are not already being used. The *presence* of the aforementioned resources (not available to everyone, of course, but for a considerable majority) is insufficient. As with all tools, they must be taken up and used, voluntarily and consistently, or their value remains latent. Musing about the same topic, Atul Gawande wrote that the problem with modern medicine is not one of ignorance, but of ineptitude[24]. That is, for the great majority of illnesses and death in the modern, developed world, 1) it is well- and widely-known what causes and prevents disease, 2) the mechanisms of prevention are cheap, available, and effective, and 3) the persistence of these pathologies is due to widespread failure to act, whether at the individual, organizational, or governmental levels.

Behavioral Science

Gawande's observation appears in his book *The Checklist Manifesto*[17], which details the astonishing success of a hospital experiment implementing a checklist system for healthcare workers to follow regarding sanitation, the checking of medication and equipment, and the consistent following of protocol during care. Doctors and nurses, it turns out, make mistakes like the rest: they forget things, rely too heavily on intuition, and occasionally misread labels. In a 21st -century hospital equipped with magnetic-resonate imaging technology, cutting edge genetic medications, and millimetrically precise robotic surgeons, a sheet of paper with boxes on it turned out to be the difference-maker vis-à-vis healthcare error, malpractice, mistreatment, and HCAI[25]s.

From Stanley Milgram's famous experiments showing how easily people would bend to authority figures[26], to Kahneman and Tversky's Nobel Prize-winning cataloguing of biases[27], to the bestsellers of Katy Milkman[28], Dan Ariely[29], and others, behavioral science takes up the tasking of answering the question: "Why do we do what we do?" Of particular importance is the question of why individuals act in a way that is inconsistent with their self-described values and goals—how a person can be aware of an option that she acknowledges to be better, and yet select an alternative. Identifying the structure of such situations, the circumstances that give rise to them, and the mechanisms that can improve decision-making under them is the goal of this research[30]. Obviously, it is not limited to topics of health: we are unnervingly prone to not saving for retirement, overusing our credit cards, destroying the environment, gambling away our paychecks, and urinating with insouciance to accuracy (see below).

Nudges

Apparently coined by James Wilk[31], and described in detail by D. J. Stewart in 1995, "Nudging" became popularized in 2008 with the publication of a book on the subject by economist Richard Thaler and legal scholar Cass Sunstein[32]. The latter define a nudge as "any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives."[25] They add that nudges ought to be easy and cheap, and that they cannot involve mandates. In short, a nudge describes a microeconomic intervention in which the presentation of options to the agent (the "choice architecture"[25]) is modified in a way such that the agent is more likely (through the exploitation of cognitive biases and heuristics) to choose *X* over *Y*.

Perhaps the most famous example of a nudge is the projection of an image of a fly in a men's urinal[33]. Researchers found that men using the urinal paid considerably more care to using the urinal in a sanitary way, presumably because the subjects were "aiming" at the fly. Though a bit unsavory, the example is useful and illustrative. First there is no restriction of individual choice, thus it is not a law. As such, it requires no political maneuvering to implement, and it requires no enforcement. Secondly, it is easy, quick, and inexpensive to implement. Thirdly, despite both previous points, it is consistently significantly effective at achieving the desired outcome. Another common type of nudge is that which relies upon the "Default Bias" such that the agent is told to do nothing if they want to choose option X[34]. For example, not submitting a formal request indicates enrollment in a retirement plan, or not opting out in a drivers' license application indicates enrollment in an organ donation plan[35].

A fourth consideration (not so relevant to the urinal example) is that nudges are easy to avoid. There are always exceptions to any general rule, and well-informed people may have an idiosyncratic rationale for pursuing an option that may not be generally recommended. For example, a financial advisor may not prefer to enroll in a company-sponsored retirement plan, as he believes he can manage his retirement fund in a more appropriate way. A nudging approach makes it relatively easy for him to opt out of the option that is generally the best choice, while still capturing the apathetic and uninformed who might otherwise neglect saving at all.

Ethical Considerations and Nudging

Unsurprisingly, Nudge Theory has given rise to an ongoing ethical debate[36]. Understanding that individuals predictably act in a particular way when presented a specific choice architecture can be (and is) used in marketing, political strategy, and other contexts in which the well-being of the actor is not the primary goal[37]. Activists, for example, allege that this is the motivating principle behind voter laws requiring photo ID[38]. That is, though it's true that acquiring an identification card is relatively cheap and accessible, certain portions of the population are statistically less likely to have done so, and the claims regarding election fraud, they argue, are merely a veneer for discouraging voter participation.

Generally speaking, the nomenclature within the field describes "nudging" as efforts to this effect that increase the probability of an agent choosing something valuable or beneficent (as judged by the agent)[28]. When the presentation of choice is structured to increase the probability of an agent choosing something harmful, the term "sludge" is used[28]. And Yanoff, in 2017[39], added the term "boost" to refer to related technique that does not so much exploit the cognitive predictability of the agent, but rather seeks to inform or educate the agent about the presence of a potentially "nudging" or "nudge-worthy" environment (that is, an environment in which there exists a predictable risk of bias or judgement-making error).

Even in the absence of ulterior or exploitative motives, some critics maintain that nudging remains unethical – after all, who is to decide what another individual *should* do[40]? Thaler and Sunstein make three points of relevance: 1) any appropriate nudge ought to orient towards the outcome that the individual him- or herself would agree is superior; 2) the ethical position of nudging – "libertarian paternalism" – is justified given the regularity with which individuals make decisions that are later regretted; and 3) "No-Nudge" is itself a sufficient position, even if it is accidental[28]. That is (to the latter point), a randomly designed choice architecture inevitably produces *some* option that is – given what is known about judgement, bias, and choice – more likely to be chosen. Thus, they suggest, it is better to design an architecture that actively seeks for that option to be a beneficent one, rather than risking it being a detrimental purely by chance.

A final consideration of relevance to public health is that nudges vary significantly in terms of their effectiveness on the basis of an agent's prior affective position[41]. Specifically, nudging tends to fail to modify behavior when an actor has a strong preexisting sentiment, either for or against *X.* This has been confirmed in experiments[42], and is intuitive: if one is, say, extremely opposed to vaccination, believing it to be toxic and a mechanism of control, a personalized text message reminder is unlikely going to change his or her mind. On the other hand, if an individual is highly conscientious with a positive disposition to healthcare, she will likely seek out vaccines, with or without a reminder. Given this, it is incumbent upon public health professionals to consider carefully the weight they give to a nudge campaign. The option of non-compliance paired with the ineffective nature on the extremely positioned will likely leave some small-but-significant portion of the population unaddressed. In situations like non-vaccination, it is precisely the extremely positioned that give rise to the concern[43] (likewise, with, say, masks and social distancing in the COVID-19 pandemic[44]). On the other hand, medication compliance may realistically be a problem of forgetfulness or something similar, and the bulk of the targeted population may be susceptible to strategic nudges.

Nudge Types

A nudge's structure is derived from a corresponding cognitive bias, heuristic, or otherwise predictable inclination. Table 1 highlights some of these, as well as providing illustrative examples of their real-life instantiation. This is by no means an exhaustive taxonomy, but underscores some of the most popular types, as well as the nudges appearing in the studies used in this review. Simply put, James Clear injuncts[45], "make it obvious, make it attractive, and make it easy."

Table 1: Nudge Types

Mechanism	General Idea	Example(s)	Intervention(s)
Default Bias/Status Quo Bias: the tendency to make no changes unless a change is required.[27]	Procrastination; taking the path of least resistance.	Procrastinating scheduling an appointment or cancelling a subscription because of an aversion to getting on the phone.	Automatically refilling prescriptions.[46] Default enrollment in organ donation program

			on drivers' license forms.[32]
Salience/ WYSIATI ("What you see is all there is"): the tendency to fail to consider anything which is not obvious or immediate.[47]	Forgetfulness; prioritizing the immediate, obvious, and urgent.	Forgetting to schedule an annual mammogram. Leaving a debit card in an ATM after grabbing out the cash.[48]	Text message reminders of upcoming appointments.[28] Signs or pop-ups alerting to act.[49] Graphical display of relevant quantitative data. Placing nutritious food near a register or at eye-level.[50]
Social Desirability Bias: the tendency to do what others are doing, to respond more pro-socially when being observed, to be motivated by the interests of others, or the desire to be admired or to fit in.[51]	Wanting to be thought well of, wanting to avoid conflict or consequences.	Drinking more at private events than at corporate events. Driving more carefully with a guest in the car than when driving solo.	Posting images of "watching eyes" in contexts of private behavior.[52] Underscoring an individual's performance in comparison to peers. Injunctions referencing aspects of social responsibility.[28]
Hyperbolic Discounting: AKA "present bias," the tendency to prefer immediate rewards to delayed ones, or to act in a way that is inconsistent with our long-term values.[53]	Consistently caving to temptation.	Committing to a diet, but having seconds when dinner is served. Committing to safe sex, but neglecting barriers in the heat-of-the-moment.	Pre-commitments: for example, ordering food ahead of time, rather than when hungry; agreeing to pay a cash penalty for not completing goals; voluntarily "self-banning" from casinos.[54]
Availability Heuristic: The tendency to make judgements of	What makes the news gets reported; *non-*	Believing driving to be safer than flying, due to frequent or recent news	Intuitive or visual explanations of accurate probabilities.

probability on the basis of how easily examples come to mind.[44]	events do not get counted.	stories about plane crashes.	Counterfactual thought experiments. Providing a flow-chart for selecting a health-care plan.[55]
Loss Aversion/Negativity Bias: the tendency to internalize negative information or outcomes more than positive ones.[56]	Assigning negative outcomes roughly twice the affective weight as proportional positive outcomes.	Losing $100 or getting ripped off for $100 contrasted with winning $100.[57]	Underscoring consequences of inaction, often with an option to act immediately. Graphic depictions of consequences, like images of diseased lungs on the front of cigarette packages.[58] Negative "framing" (see below).
Framing: the tendency to interpret economically or mathematically equivalent information based on scenario; to be subconsciously influenced by environmental cues.[44]	Shifting norms, goals, or evaluative criteria on the basis of perceived circumstantial appropriateness.	Refusing an operation that has a 10% death rate, but accepting an operation that has a 90% survival rate.[59] Giving more generously when in a familial environment than when in a corporate environment.	Presenting information with a positive spin when something ought to be done, and with a negative spin when it ought not be. Placing "just-cleaned" aroma dispensers in environments needing to stay tidy. Placing images of flies on the basins of men's urinals.

Hand Hygiene

This thesis will explore the ways in which this concept of nudging has been deployed in public health interventions to promote hand hygiene and will estimate their efficacy. As far as "nudgeable" outcomes go, hand hygiene offers a nearly perfect target: 1) it is (at least in the developed world, though increasingly elsewhere*) ubiquitously accessible[60], requiring no advanced knowledge or technology; it is not prone to controversy, nor to affective extremes[61]; 3) compliance is in the interest of the agent; and 4) it is inexpensive and highly effective[62]. Indeed, the World Bank considers hygiene in general to be the most cost-effective intervention for reducing the global healthcare burden. Put simply, it is likely that biases, heuristics, or choice-architectural idiosyncrasies (inconvenience, forgetfulness, etc.) are to blame for imperfect compliance[63].

The costs of this noncompliance are high. Globally, it is estimated that 1 million deaths per year could be prevented with effective hand hygiene (including 50% of all deaths related to diarrheal diseases)[64]. The transmission of foodborne diseases and seasonal respiratory infections including cold and influenza can be significantly influenced by the extent of adequate hand hygiene[61]. Even when non-lethal, these sicknesses contribute to work and school absenteeism[65], carrying dramatic costs economically, socially, and educationally. In clinical environments, healthcare practitioners clean their hands only around half-as-often as is recommended by the CDC[66]. As a consequence, approximately 3% of all hospital patients at any given time have a HCAI[67]. Of course, the widespread initiatives, PSAs, and reminders accompanying the COVID-19 pandemic further highlight the necessity of good hand hygiene, despite being amplifications of what public health experts irrespectively endorse.

Hand hygiene does not correspond to a singular act – say, washing with water and soap—and any of these dimensions may be considered. For example, “hand hygiene” encompasses glove-wearing in clinical settings, hand-sanitizing, context-specific guidelines (e.g., before handling food, after using the restroom), duration of time spent scrubbing, temperature of water, and even fingernail length[68]. Thus, interventions could in theory target any or all of these (or others still) as outcomes. However, given that 2/5 Americans report failing to wash their hands after using the bathroom[69], researchers could be forgiven for starting with simply washing or sanitizing. Predictably, this was the outcome measured in the majority of the studies included in this review.

* UNICEF reports 71% of the global population having handwashing facilities with soap and water available *in the home*, and did not report on availability elsewhere (work, school, etc.).

Chapter 2: Literature Review

As suggested above, researchers have noticed the applicability of nudging in a variety of healthcare-related practices and domains. Prior literature has explored – in addition to hand hygiene – using nudges to promote medication compliance, wellness visit consistency, cessation of substance abuse, safer driving habits, exercise and activity promotion, and so on[70]. The COVID-19 pandemic saw a wave of creative implementations as well: text-message campaigns to encourage vaccination, widespread signage encouraging distancing and mask compliance, and a wide variety of modest incentives (from cash to free beer!) for testing and/or vaccination[71], and more. At more abstract levels, nudges have been explored in things like health insurance plan selection and estimating susceptibility to disease. Several universities have created centers and initiatives for researching nudges in health contexts, including the University of Pennsylvania's Perelman School of Medicine's Nudge Unit[72]. Similarly, governments have also established comparable institutions for policy advisement that includes advisement on health-related topics.

This abundance of research has likewise produced a number of SRMAs synopsizing findings and estimating effects. A 23-study review on promoting fruit and vegetable consumption found a moderate positive effect in 2017[4]. A more general review in 2016 found a slight improvement in overall dietary quality with nudging[73]. Zlatevska, et al., summarized literature relating to using smaller portion-sizes or serving dishes on number of calories consumed, also reporting a modest positive finding[74]. Cardario and Chandon performed a meta-analysis of experiments themselves, seeking to identify which nudges conferred the greatest effect on dietary choices, finding that behavioral interventions to discourage unhealthy eating were most effective[75].

Obviously, not all meta-analyses have explored healthy eating. A 2021 meta-analysis on the use of nudges to overcome vaccine hesitancy found mixed results[76]. Though not a meta-analysis, Katherine Milkman spearheaded a 680,000+ person "mega-study" on the effect of nudging to promote flu vaccination[77]. Using a text-message system generating personalized text-message reminders, the team found an increase of about 7% over the control portion. In 2021, Mertens, et al, published what might be called a "meta-meta-analysis" in which nudges were assessed for effect on the basis of the *domain* of the target: health, education, personal finance, etc.[78] They found that among 84 then-eligible effect sizes there was a modest, but significant, effect towards the desirable outcome across a pooled sample of 122,762 ([d = .34], 95% CI = [0.22 – 0.45].[74] Oddly, "food" was considered a different category of nudge, but was found to be even more positive in effect: 111 effect sizes with 12,515 total participants finding d=.72, 95% CI = [.49 - .95].

Despite this breadth of research, the review of literature failed to identify any extant SRMAs that addressed the efficacy of nudging interventions in the promotion of hand hygiene. The details of the included and relevant literature are explained in the sections that follow. However, it is worth mentioning that across a variety of registries, a number of RCTs were identified that would shed light on the target of this review that were—at the time of writing – incomplete. (These studies are listed in Appendix 1.) Once these results are in, the consideration of their findings ought to shed even more light on the question of nudges' efficacy in promoting hand hygiene.

Chapter 3: Methodology:

Systematic Review

A research review (or "narrative review") is an attempt to cast a wide net through extant literature, capturing and summarizing the findings across multiple studies for the purpose of synopsizing the state, efficacy, and impact of a particular intervention or field[79]. A *Systematic* Review represents a refinement of this process. As one pair of researchers[80] put it: "A systematic review is a summary of the …literature that uses explicit and reproducible methods to systematically search, critically appraise, and synthesize on a specific issue. It synthesizes the results of multiple primary studies related to each other by using strategies that reduce biases and random errors." Thus, one might say that the "System" is the essential component of differentiation. Multiple professional and standards commissions have arisen to provide guidance on the performance on these reviews, including the Campbell Collaboration[81], Cochrane[3], PRISMA[82], and others. The Campbell Collaboration materials hosted on the Open Learning Initiative at Carnegie Mellon University (OLI) defines it in this way:[83]

(Systematic Review) is:

- a distinct form of research which
- uses explicit criteria and transparent replicable procedures
- to identify, assess, and synthesize results of multiple studies
- in order to address a central research question,
- while minimizing bias and error at each step in the review process.

Harris Cooper and OLI outline seven steps that a systematic review must follow, specifying step-specific standards by which researchers must abide to ensure integrity, replicability, and bias-reduction:[80]

1) Problem Formulation – including defining inclusion criteria, establishing a satisfactory team, and developing a protocol for research.
2) Searching the Literature – comprehensively, including searches for "grey literature" (research that is unpublished (in the "file-drawer") or that is published in or under unusual circumstances).
3) Screening Potentially Eligible Studies – using structured and predefined tools.
4) Data Extraction and Coding – with protocols for establishing and resolving issues related to interrater agreement.
5) Critical Appraisal – using explicit and justified metrics of primary study validity.
6) Meta-Analysis – see below.
7) Report Preparation – using documented methods, and reporting the details of the procedure, decisions, and composition sufficiently for an external researcher to replicate the process.

Where the body of this review does not explicitly and adequately address these criteria, further details are provided in described appendices.

Meta-Analysis

Pioneered by Gene Glass and Mary Lee Smith in 1976 and 1977[84], this methodology involves the pooling of measures of statistical impact from a disparate body of evidence produced in previously published studies and experiments. Meta analysis 1) is characterized by the evaluation and summarization of multiple studies; 2) contextualizes effect size across various times, places, and researcher teams, thus expanding external validity; 3) considers variegated sample sizes, contexts, and methodologies allowing for the standardization of potential sources of bias, outliers, and other methodological noise, thus expanding internal validity; and 4) yields benchmark references that reflect the average significance of the interventions they study[80].

Population, Intervention, Comparison, Outcome, Study (PICOS)[85]:

Eligibility criteria for studies included in this SRMA were the following:

1) Populations: No exclusions were based upon age, race, gender, profession, nationality, country of origin, country of study, or profession. While exclusion was permitted on the basis of language of publication (limited to English), this nevertheless included populations from multiple non-English-speaking countries, including Bangladesh, Thailand, The Netherlands, Norway, Slovenia, and Denmark. Roughly, this represented four categories of population: healthcare workers, schoolchildren, visitors (to healthcare related facilities or in public locations), and organizational-affiliated adults (for example, military personnel on a military base). Though these weren't explicitly specified as contexts or populations for inclusion, their emergence is unsurprising, as these environments (healthcare settings and large gatherings of unrelated people) are where hand hygiene-related disease transmission is most probable.
2) Interventions: The principal restriction upon interventions was that they were consistent with the criteria set out by Thaler and Sunstein, namely that they were cheap to implement, easily avoided, and non-coercive. Relatedly, since the focus of this paper is *nudging*, only those papers in which the authors described their intervention as having been inspired by or derived from *Nudge Theory* (or implied it through nomenclature and referenced literature) were included. *Title and Abstract Screening*, below, discusses this in more detail, but the essential rationale is that what a researcher does not consider a nudge could easily *look like* a nudge, while in fact being derived from a quite different theoretical framework. Put simply: it was decided that not every cheap and non-coercive attempt to promote hand hygiene qualifies as a *nudge*.
3) Comparison: All included studies were required to have a quantitative effect size describing a difference between a group being nudged and a group not being nudged with respect to the targeted outcome. In some cases, these groups were established via random assignment, but the majority of the studies were quasi-experimental, using single- and multi-arm pre-post designs[86]. For example, measuring hand disinfection routine compliance amongst a group of healthcare workers before and after a nudge, or measuring frequency of hand-hygiene amongst hospital visitors in a given month (with no nudge) versus visitors in the following month (with a nudge).
4) Outcomes: No restrictions were made in terms of the outcome of measure, provided it was related to hand hygiene. As mentioned above, in principle this could cover a wide variety of outcomes, but in practice it was found to be handwashing, hand-sanitizing, handwashing *with soap*, or compliance with a specified protocol of hand-disinfecting steps. Specifically, this was

measured either before entering a potentially high-risk environment (e.g., a hospital), or after a potentially unsanitary activity (e.g., sneezing, restroom use). That being said, details below outline certain judgements that were made with respect to eligibility vis-à-vis insufficiently reported quantitative data, and/or metrics of atypical outcomes (specifically, measurements of the volume of hand-sanitizing substance missing over time, rather than a count of observed instances of compliance).

5) Studies: The study design, as mentioned, typically followed a pre-post quasi-experimental format. In single-arm studies, the most common format was one in which a specific population was randomly selected (e.g., physicians and nurses on a given hospital ward or floor), then observed complying with hand hygiene protocols during a non-intervention interval versus an interval in which they were nudged. In some cases, this was itself followed by additional intervals using different nudges or multiple nudges in combination. The multi-arm studies did the same, but with groups established based upon day or time of visit. Studies in which nudges were discussed, but in which no intervention was performed were excluded, as were studies which only reported interventions consisting of nudges *and* some additional intervention (for example, hand hygiene educational modules).

Literature Search

Search was performed on the following databases: Databases: PubMed, EBSCOhost, Cochrane Library, and Google Scholar. Further external resources that were perused for possibly relevant materials included the University of Pennsylvania's Perelman School of Medicine- Nudge Unit, The Agency for Healthcare Research and Quality, greylit.org, Canadian Electronic Library, CHODARR, and opengrey.eu Cochrane Training, and Carnegie Mellon University's Open Learning Initiative *Systematic Review* course.

Search terms consisted of "Nudg*," "Health," "Hand," "Wash*," "Hygiene," "Choice Architecture" and "Sanit*." Combination search terms used were: '''Nudg*'' AND ''hand'' OR "health"'' OR ''''Nudg* AND ''wash*'''' OR '''''Nudg*'' AND ''sanit*'''' OR '''''Nudg*'' AND ''hygiene'''' OR ''''Choice Architecture" AND "hand"" OR ''''Choice Architecture'' AND "wash*"" OR """Choice Architecture" AND "hygiene"" OR """Choice Architecture" AND "sanit*"".

The following criteria were used to guide and inform the literature search:

-Published after 2008*
-Publication in an OECD Country (irrespective of country of study)
-No indication of retraction or significant corrigenda
-Published in English

As a limited example of the search process, on EBSCOhost, full text Boolean search, limited by year 2007 or after, English language, and excluding non-academic databases, "TX Nudg* AND TX Hand AND TX(Wash* OR sanit* OR hygiene) = 84,071 matches. Refinements restricted to academic articles, books, reports, and conference materials produced 14,908 matches. Finally, restricting to empirical, quantitative, field, or longitudinal studies, or literature or systematic reviews, or replications, clinical

* This being the year that Thaler and Sunstein published "Nudge," thereby introducing the term into common usage and conferring its contemporary meaning in microeconomic research.

trials, or meta-analyses yielded 85 matches. Comparable search on Google Scholar found 128 matches. Comparable search on PubMed yielded 47 results. Additional Search performed on greylit.org, Cochrane Library, University of Pennsylvania's Perelman School of Medicine- Nudge Unit, The Agency for Healthcare Research and Quality Canadian Electronic Library, CHODARR, and opengrey.eu found no relevant additional documentation.

Title and Abstract Screening

All eligible papers were imported to Zotero[87], where duplicates and retracted articles were deleted. and the remaining articles were screened by title and abstract, after which 58 studies remained which were determined to be eligible for full-text review. During screening, two studies were identified that had performed prior narrative or systematic reviews of nudges related to factors of hygiene, one in the context of food preparation[88] and the other in terms of clinical practice.[89] Where these summaries referenced published studies on hand hygiene, those studies were also examined. Four of the prior studies were already captured in the extant search results. Of the remaining eleven, none made reference to having been inspired or designed with respect to Nudge Theory (presumably why they were not captured in the previous search process). That recently published reviews found no studies undiscovered in the literature search further verifies the thoroughness of the search process. Likewise, the search yielded several master's theses, pre-prints, and other potentially grey literature forms, further suggesting comprehensiveness of literature review.

The content of the title and abstract screening tool can be found in Appendix 2, but the most impactful criteria were that the study was an experimental intervention, that the nature of the intervention was identified as a nudge, and that the authors reported a quantitative effect size measure. The majority of studies that were deemed to be ineligible were those that implemented interventions that were consistent with the definition of a nudge, but which described neither the intervention nor the theoretical framework in terms of nudging. For example, UNICEF's Water, Sanitation, and Hygiene (WASH) program was referenced in one[90], while others made reference to the Health Belief Model (HBM)[91] and the Extended Parallel Processing Model (EPPM)[92]. Given that the scope of this review references the efficacy of *"nudges,"* interventions consistent with the definition but without the theoretical framework at best answer one-half of the question, thus they were excluded from the meta-analysis. That said, the consistency of the interventions with the definition of a nudge sheds light on the absolute effect of the intervention when implemented, and may be amenable to modification or recharacterization in future studies, and may be found in Appendix 1. Two studies were identified in which the authors explicitly referenced nudging/nudge theory, and where the outcome was a quantitative measure of hand hygiene, but full text review found the substance of the intervention to fail to meet the definition of a nudge. That is, the "nudge" either was an inaccurate descriptor for an intervention that included multiple components of an educational and interactive program, or the nudge was only presented in conjunction with these types of broader interventions. Three papers identified all made reference to the same study population, approaching the intervention from multiple lenses[93,94,95]. This data was included, but only once. Figure 2 below[96] illustrates the search, selection, and inclusion process.

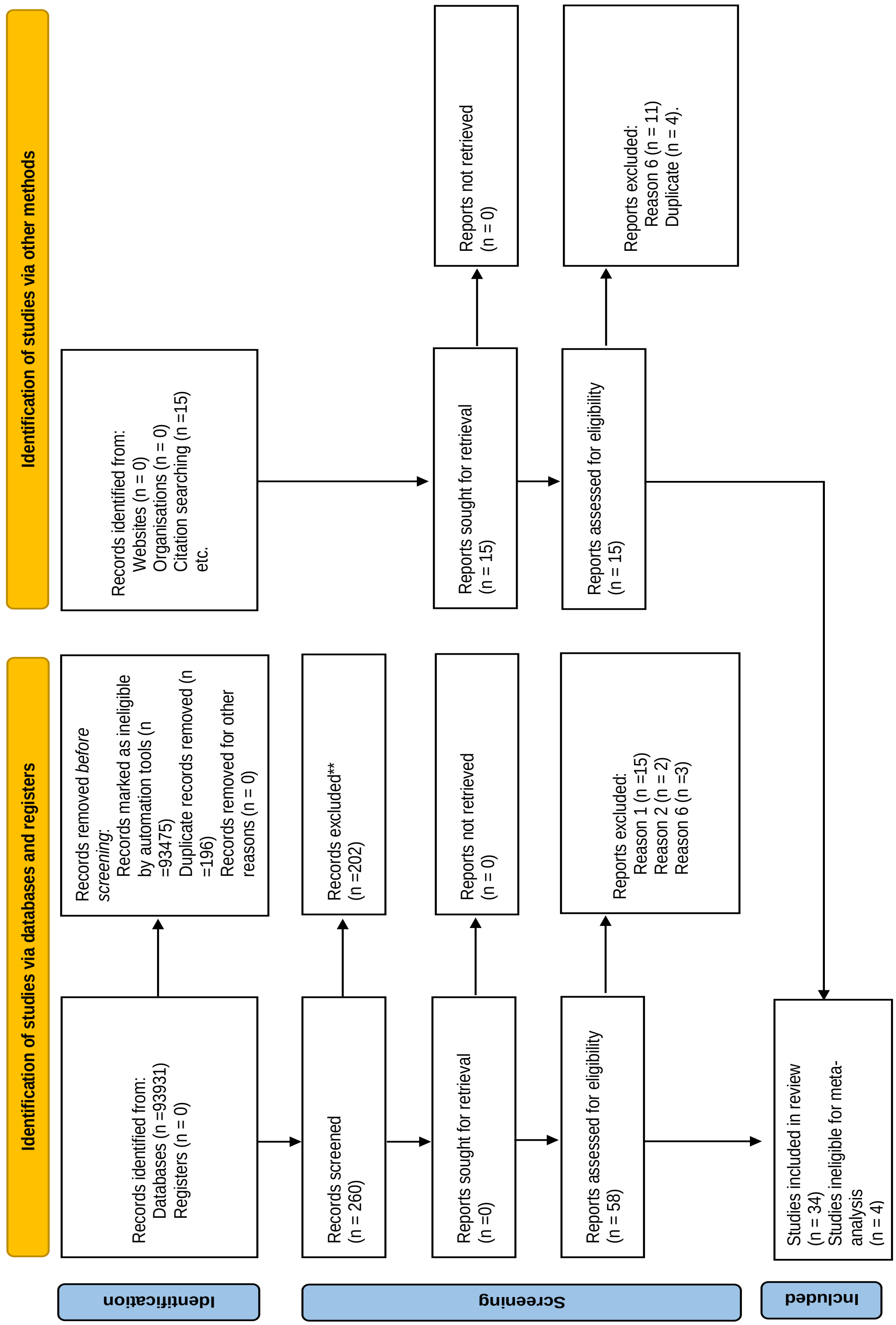


Figure 1: PRISMA Literature Search Diagram*

*"Reasons" referenced herein may be matched to descriptors in the screening tool in Appendix 2.

Full-Text Review and Data Extraction

Studies varied in terms of outcomes, complicating estimates of effect size. Specifically, some studies measured in terms of the number of handwashing/hand-sanitizing instances, others in terms of the compliance with a particular hand-disinfecting procedure (use of gloves, sequence of hand-hygiene practices, duration of time spent washing, and so on), and still others in terms of the volume of hand-soap/-sanitizer used. While all included studies include some form of effect size, the inconsistency of outcome metric may pose a challenge in terms of external validity. Thus, these studies were excluded from statistical summarization, but may be found in Appendix 1. Not included in Appendix 1 were studies that appeared to meet criteria, but were found, upon closer inspection, to be theoretical or preliminary – e.g., quantitative data on a nudge, but dealing with affect (for example, "Please estimate how much nudge affected you").

Another complicating component of some studies was that they tested multiple nudges in an additive way. For example, a no-nudge baseline week may be compared to a week with a salience nudge, a week with an ease nudge, and a week with a salience *and* ease nudge. Since the scope of this review is not comparing nudges by type, but summarizing nudging in general, these were computed as simply separate dependent effect sizes (i.e., each was compared to the baseline, then was folded into the summary weighted effect size with adjustments for dependent effects). Generally speaking, this was found suitable on the basis of the facts that sample sizes were comparable, and there was no ostensible linearity between number of nudges and outcome efficacy. Similarly, some papers included follow-ups for intervals after the nudge was removed, attempting to test for the durability of the effected change. These data were not included in the MA. The data extraction codebook is available as Appendix 3.

The following table summarizes the studies selected, indicating the year of the study, the country in which the study was performed, the setting or context in which the nudge was implemented, the intervention or type of nudge used, the duration of the study, the sample size or event count, the outcome being measured, and the principal quantitative findings.

Author(s) Country Year	Setting/Design	Intervention(s) /Nudge-Type	Duration	Sample Size: N=	Outcome Measured	Quantitative Summary:
Aarestrup, et, al, 2016 Denmark[97]	At the entrance to a hospital, use of a hand sanitizer dispenser was measured for baseline, with a sign encouraging hand sanitizer use, and with an additional message about safety for relatives.	Reminder Social Desirability	5 Days	90	Proportion of entrants using hand sanitizer upon entering a hospital	Baseline: 3% Intervention_1: 20% Intervention_2: 67%
Deshmukh, et al, 2019, India[98]	In a school, a wall-mounted "social robot" reminded students to wash their hands after using the restroom and before eating.	Salience	9 Days	100	Proportion of key times for handwashing where hands were washed.	Baseline: 25% Intervention: 65.45%
Dreibelbis, et al, 2016, Bangladesh[99]	At a school, a handwashing station was erected near the lavatory. Baseline was taken, then a short footpath was added (intervention_1), and then colorful footsteps were painted leading to the station (Intervention_2).	Salience	6 Weeks	734	Proportion of post-lavatory handwashing opportunities taken.	Baseline: 4% Intervention_1: 68% Intervention_2: 74%

Grover, et al, 2018 Bangladesh [100]	Across 10 different schools, baseline was taken for 2 groups of 5 schools. Subsequently, 5 schools received simultaneous nudges of a path, bright paint for the wash station, hand-prints on the wash station, a dedicated soap dispenser, and arrows/footprints leading to the station (Intervention_1). Another group was nudged in the same way, but sequentially, with one nudge added after another.	Salience	6 Months	3722	Proportion of post-lavatory handwashing opportunities taken.	Baseline_Group_1: 28% Intervention_Group_1: 54% Baseline_Group_2: 17% Intervention_Group_2: 63%
Hansen, et al, 2021, Denmark[101]	In a sequence of combinations, a total of 9 different variations of nudging were contrasted with a baseline, where the outcome was hand sanitizer use upon entering a hospital.	Salience Social Desirability Loss Aversion/Negativity Bias	50 Days	46,435	Proportion of entrants who sanitized hands upon entering hospital.	The individual configuration counts can be found in Appendix 4, but in summary: Baseline: <1% Average of Interventions: 9.8%
King, et al, 2016 United States[102]	At a teaching hospital in Miami, hospital employees were observed for use of hand-sanitizer upon entering an intensive care ward. Intervention_1 was nudged with a citrus fragrance, while intervention_2 was nudged with an image depicting "watching eyes"-- a cropped image of human faces.	Priming (Olfactory) Social Desirability	3 Months	404	Proportion of instances of entering the ward that were accompanied by hand-sanitizer use.	Baseline: 15% Intervention_1: 46.89% Intervention_2: 21.67%

Mlakar, et al, 2017 Slovenia[103]	In a nursing home, nursing home staff were monitored following patient interactions for compliance with hand-disinfecting protocols (control). Afterwards, the addition of a "watching eyes" image was placed near locations where interactions were taking place (Intervention).	Social Desirability	5 Months	8	Proportion of instances of compliance with full hand-disinfecting procedure following occupant interactions.	Baseline: 56.29% Intervention: 60.74%
Mobekk & Stokke, 2020 Norway[104]	At the entrance to a hospital, a hand sanitizing dispenser was dispensed alone, with a sign indicating that it was the norm to clean hands before entering (Intervention_1), and with an additional sign suggesting that hand sanitizing was for the safety of relatives (intervention_2).	Salience Social Desirability		300	Proportion of entrants using hand sanitizer upon entering a hospital	Baseline: 7% Intervention_1: 46% Intervention_2: 40%
Naluonde, et al, 2019 Zambia[105]	In 25 schools, business-as-usual practices were accompanied by counts of post-restroom hand-washing instances (control), while in 25 other schools, students leaving class for the restroom were given a "hall-pass" of hand-soap tied to a wearable lanyard (Intervention).	Salience	4 Months	10,732	Proportion of lavatory uses that were followed by hand-washing (Intervention_1), and proportion of students who used soap (Intervention_2)	Baseline_1: 58.4% Intervention_1: 60.09% Baseline_2: 47.5% Intervention_1, Outcome_2: 50.3%
Palinko, et al, 2021, Denmark[106]	At the entrance to a hospital cafeteria, a standard-fare hand-sanitizer dispenser (control) was compared to a robotic-interface dispenser (Intervention).	Salience	2 Days	363	Proportion of entrants using hand sanitizer upon entering a cafeteria.	Baseline: 47% Intervention: 68%

Pfattheicher, et al, 2018 Germany[107]	Near the sink in a women's restroom, an image of "watching eyes" was placed on the wall.	Social Desirability	1 Week	354	Proportion of women who, upon using the restroom, washed hands before leaving	Baseline: 72% Intervention: 83.3%
Weijers & de Koning, 2021 The Netherlands[108]	In an outdoor shopping area, during the COVID-19 pandemic, a table was setup outside of a shop with a hand sanitizer dispenser available (control). Later a sign was added advertising availability, and arrows were placed on the ground pointing the stand out (intervention_1). After, a different sign was used that emphasized the risks associated with un-sanitized hands vis-a-vis COVID-19 (Intervention_2).	Salience Loss Aversion/Negativity Bias	3 Days	451	Proportion of store entrants who used hand-sanitizer.	Baseline: 33.3% Intervention_1: 42.5% Intervention_2: 37.7%
Wichaidit, et al, 2020, Thailand[109]	In multiple areas in a hospital, hospital visitors were observed engaging in activities that justified hand-disinfecting. Afterwards, pedal-operated sanitizer stations with signs and footprint images encouraging use.	Salience	9 Days	466	Proportion of events warranting hand disinfecting taken.	Baseline: 0% Intervention: 19%
Wiik, 2019, Norway[110]	At the entrance to a mess hall on a military base, 2 baseline measures were taken: one for whether hands were washed with soap prior to entering, and a second for whether hands were sanitized or not. The intervention of signage varied in message via frequent rotation, with varying messages.	Salience Social Desirability	2 Weeks	480	Proportion of individuals washing/sanitizing hands upon entering a mess hall.	Baseline_1: 90.4% Intervention_1: 97.09% Baseline_2: 52.17% Intervention_2: 37.86%

Statistical Analysis:

Odds Ratio[111]

Given the familiar epidemiological 2x2 table , the odds ratio (OR) is given by the formula:

		Outcome	
		Yes	No
Exposed	Yes	**a**	**b**
	No	**c**	**D**

Figure 2: 2x2 Table

$$(3) \qquad OR: (a/b)/(c/d) \; = \frac{ad}{bc}$$

That is, the odds ratio is the odds of experiencing an outcome given and exposure, divided by the odds of experiencing the same outcome given non-exposure. As the performance of meta-analytic summary requires that included studies possess – or offer sufficient data-related detail to infer— a common outcome-metric, 4 studies were deemed eligible by all existing criteria, but were excluded from analysis because of the manner/level of detail provided. These are discussed below. No attempt was made to contact the authors for additional details.

As the OR cannot, by definition, be negative, but simultaneously has no upper limit, analysis is conventionally performed on the log odds ratio (LOR), which is then exponentiated for interpretative purposes.

$$(4) \qquad Log\ Odds\ Ratio = ln(OR) = log_e\left(\frac{ad}{bc}\right)$$

and

$$(5) \qquad Odds\ Ratio \; = \; exp(ln(OR)$$

The standard error of which is estimated with the root of the sum of the reciprocals of *{a, b, c, d}:*

$$(6) \qquad SE\big(ln(OR)\big) = \sqrt{(1/a) + (1/b) + (1/c) + (1/d)}$$

With corresponding confidence interval of:

$$(7) \qquad \mathrm{CI} = \mathrm{e}^{\left[\ln(OR) \pm 1.96\left(\sqrt{(1/a)+(1/b)+(1/c)+(1/d)}\right)\right]}$$

The majority of eligible papers presented odds ratios and/or explicit counts from which odds ratios were easily derived. In some cases, means or proportions had to be used to convert the results into odds ratios when other measures of effect were reported. All of the relevant counts were formatted into 2x2 tables, and the Practical Meta-Analysis Effect Size Calculator (from Wilson, George Mason University)[112] was used to compute the OR, 95% CI, log-OR, and Log V-OR. These data were uploaded into a spreadsheet that can be found in Appendix 4.

Inverse-Variance Weighted Average[113]

The output of a meta-analysis is an average effect size, which is computed from the individual studies' effect sizes, weighted by their precision. Generally, this computation is performed in concordance with the Inverse-Variance Weighted Average: the assignment of greater weight to (usually larger) studies which have lower standard errors. For example, the fixed effect model is given by the equation (where k = the number of studies):

$$(8) \qquad \overline{ES} = \frac{(\sum_{i=1}^{k} w_i ES_i)}{(\sum_{i=1}^{k} w_i)}$$

With the following standard error:

$$(9) \qquad SE_{\overline{ES}} = \sqrt{\left(\frac{1}{\sum w_i}\right)}$$

And with upper- and lower-confidence intervals defined by:

$$(10) \qquad \overline{\mathrm{ES}_{\mathrm{u/l}}} = \overline{ES} \pm Z_{(1-\alpha)}\left(SE_{\overline{ES}}\right)$$

This estimate, however, assumes a "fixed" effect – that population parameter is a constant, yet-undiscovered effect. To explore this assumption, homogeneity tests are typically performed to estimate the extent of variation in effect size between studies. This is frequently given by the *Q-Test:*

$$(11) \qquad Q = \left(\sum_{i=1}^{k} w_i {ES^2}_i\right) - \frac{\left(\sum_{i=1}^{k} w_i ES_i\right)^2}{(\sum_{i=1}^{k} w_i)}$$

Also, the *I-Squared* index provides a relative descriptive estimate of the extent of difference explainable by random effects as opposed to true heterogeneity:

$$(12) \qquad I^2 = \left(\frac{Q-df}{Q}\right) x100\%$$

In this study, a number of factors were identified that required modification and/or deviation from the standard fixed effects analysis described here. While the general logic remains unchanged, the specific implementation herein is described in the following section.

Random, Dependent, and Multivariate Effects

Firstly, given the diversity of the study contexts and participants, the data in this analysis do not warrant the assumptions of the fixed effect model. Thus, this study uses the so-called *Random Effects Model*[114], which incorporates a weight that additionally accounts for the inter-study variation. This weight is described by:

$$(13) \qquad \frac{1}{var_{fixed}+\tau^2}$$

While the model implemented through metafor in this analysis uses a *Restricted Maximum Likelihood*[115]*,* a related computation for the *Tau-Squared* value in the denominator is given by:

$$(14) \qquad \tau^2 = \frac{Q-(k-1)}{\sum w_i - \frac{\sum w_i^2}{\sum w_i}}$$

Likewise, using *Tau-Squared* permits the calculation of a heterogeneity prediction interval, which is less fraught and more descriptive than the *I-squared* value presented above (where $t_{crit_{k-2}}$ is the corresponding critical value with k-2 degrees of freedom):

$$PI = \overline{ES} \pm t_{crit_{k-2}} \sqrt{\left(var_{\overline{ES}} + \tau^2\right)} \quad (15)$$

Secondly, while the random effects model accommodates variation more suitably, it does not – on its own – account for intra-study correlations of effect size. That is, many of the identified studies reported multiple, dependent effect sizes—either by comparing multiple treatment groups to a single control, or by reporting multiple outcomes for the nudged intervention. In the past, this type of issue has been resolved using *Unit-of-Analysis Shifting*[116] or *Synthetic Effect Sizes*[117]. However, the former requires that each individual effect size be linked to a corresponding control group (which is not the case in all of the studies described herein), and the latter requires effect size estimates relating to distinct outcomes (which is not the case in any of the included studies). Thus, to accommodate the multiple and dependent effect sizes in this dataset, meta-regression techniques are deployed to bypass assumptions of non-correlation within effect sizes. Specifically, a multivariate random effects model using an imputed variance-covariance matrix and *Robust Variance Estimation* (RVE) is deployed. The full details of these techniques are beyond the scope of this review, but may be perused in Hedges, et al (2010)[118], Rodgers and Pustejovsky (2021)[119], Veichtbauer (2010)[120], and Fisher, et al, (2017)[121].

Chapter 4: Results

In total, 14 studies – contributing a total of 34 effect sizes – were analyzed using R (version 4.1.2[122]), and the metafor[1] and clubSandwich[2] packages. The initial composite median log odds ratio estimate was 1.6178 (OR = 5.042), with an interquartile range of 1.875 (OR= 6.524). Applying the random effects model, the unadjusted average effect was 1.5664 (OR = 4.789), with a 95% confidence interval = [1.113 – 2.0216] (OR = [3.043 – 7.55], p <.0001). Tests of heterogeneity found I^2= 98.77%, τ^2 = 1.7036 (SE = .4477), and *Q* = 1972.01 (p < .0001).

Multivariate Model with Imputed Covariance Matrix

Continuing with the multivariate model using the imputed covariates, the average effect was 1.416 (*SE* = .2987, *z* = 4.74, p <.0001, 95% CI [.8307 – 2.0015]). The prediction interval estimated with the "predict()" function in metafor was found to be = 1.416, with bounds at (-1.066 – 3.898). The study-level variance (τ^2) was estimated equal to 0.61, and the within-study variance (ω^2) was estimated equal to 0.90. In terms of heterogeneity, *Q* was estimated at 4616.9043 (p <.0001). Figure 16, below, shows the Forest plot for this model.

The RVE was estimated at: Intercept = 1.42 (SE = .301, df = 11.5, p <.001). The total variance, including both within-study and between-study variance, was estimated (calculated with sigma^2.1 + sigma^2.2) = 1.514, with corresponding prediction intervals (calculated as meanLOR ± 1.96*(total variance) = [-1.5518 – 4.3839].

Publication Bias

The *Egger's Test for Funnel Plot Asymmetry* found z = 2.4682 (p=.0136), with a limit estimate of b = 0.9495 (CI: .0318 – 1.5971) (see Figure 17 below). The null hypothesis of Egger's Test is that symmetry is present, thus significance – as found here—suggests possible asymmetry due to publication bias. Similarly, the contoured funnel plot is generated assuming effect sizes are independent, under which (see Figure 18 below) few of the studies were found to fall inside of an insignificance-indicating region. The absence of studies failing to meet a significance threshold further reinforce possible publication bias.

On the other hand, the "Egger's Sandwich" test (used to discern the extent of correlation between effect size and sample size) uses a regression model fit with cumulative sample size as a predictor and effect size as an outcome. A negative, result, then would indicate a tendency for small samples to be responsible for larger effects, possibly obfuscating the true effect size of the intervention. The intercept estimate for this model = 1.124, SE = .32 (t-stat = 3.5, Satterthwaite =11.44 (p = .0047)), with a regression coefficient for sample size = .0000141, SE = .0001 (t-stat = 1.33, Satterthwaite = 1.42 (p=.349). The closeness of this regression coefficient to zero is inconsistent, then, with some patterns of publication bias, possibly bolstering confidence in these findings

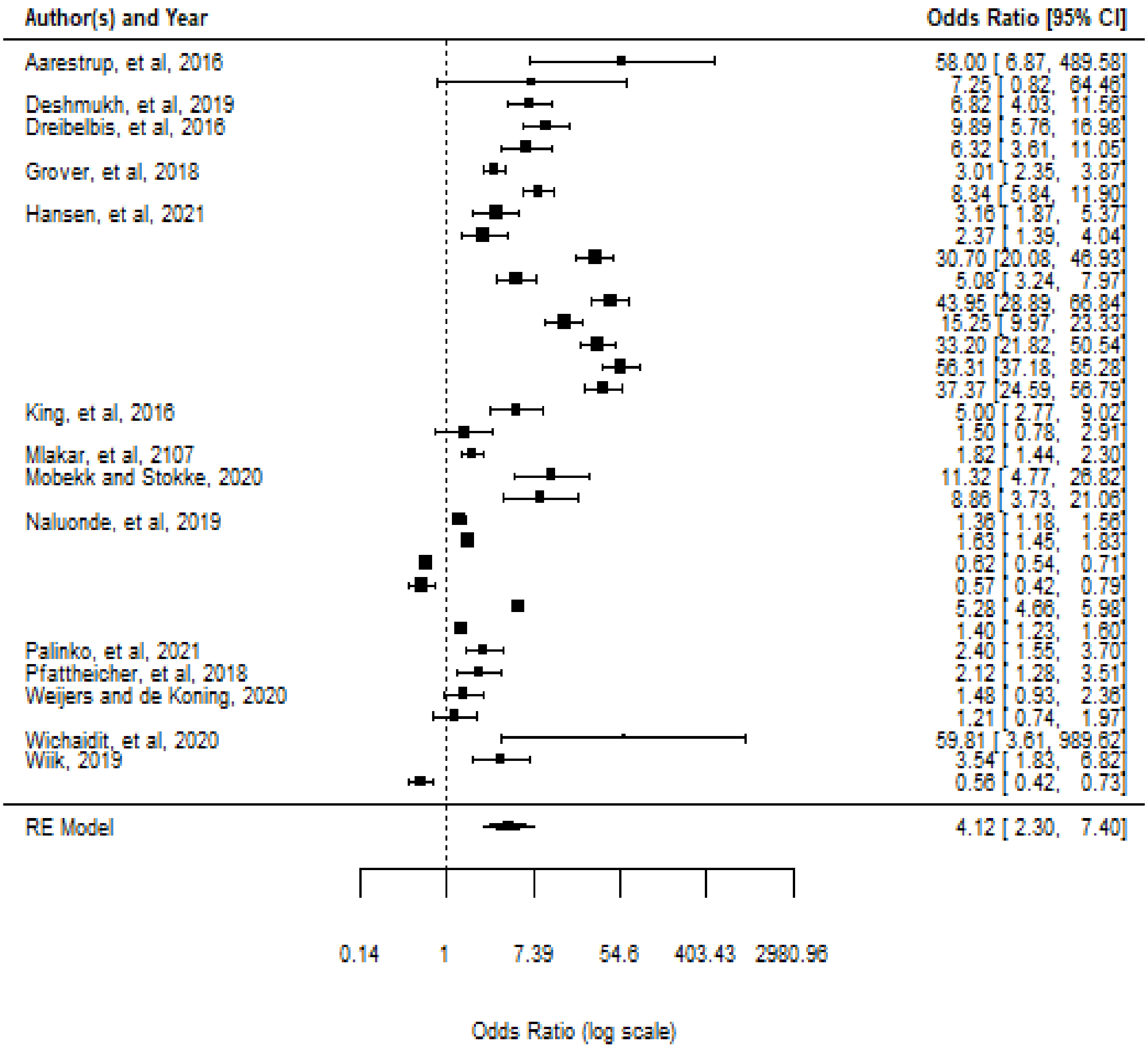


Figure 16: Multivariate Random Effects Model

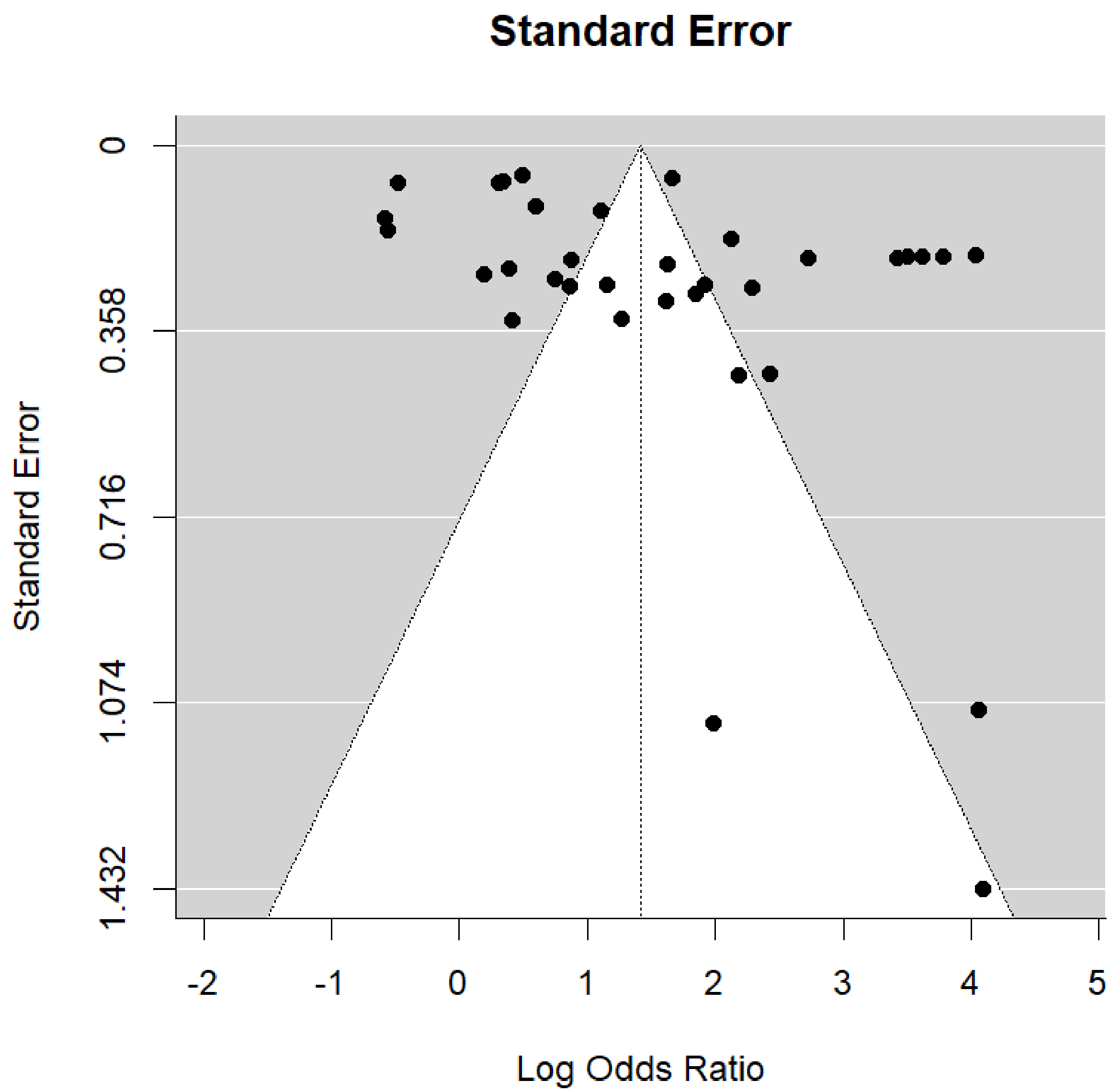


Figure 17: Traditional Funnel Plot

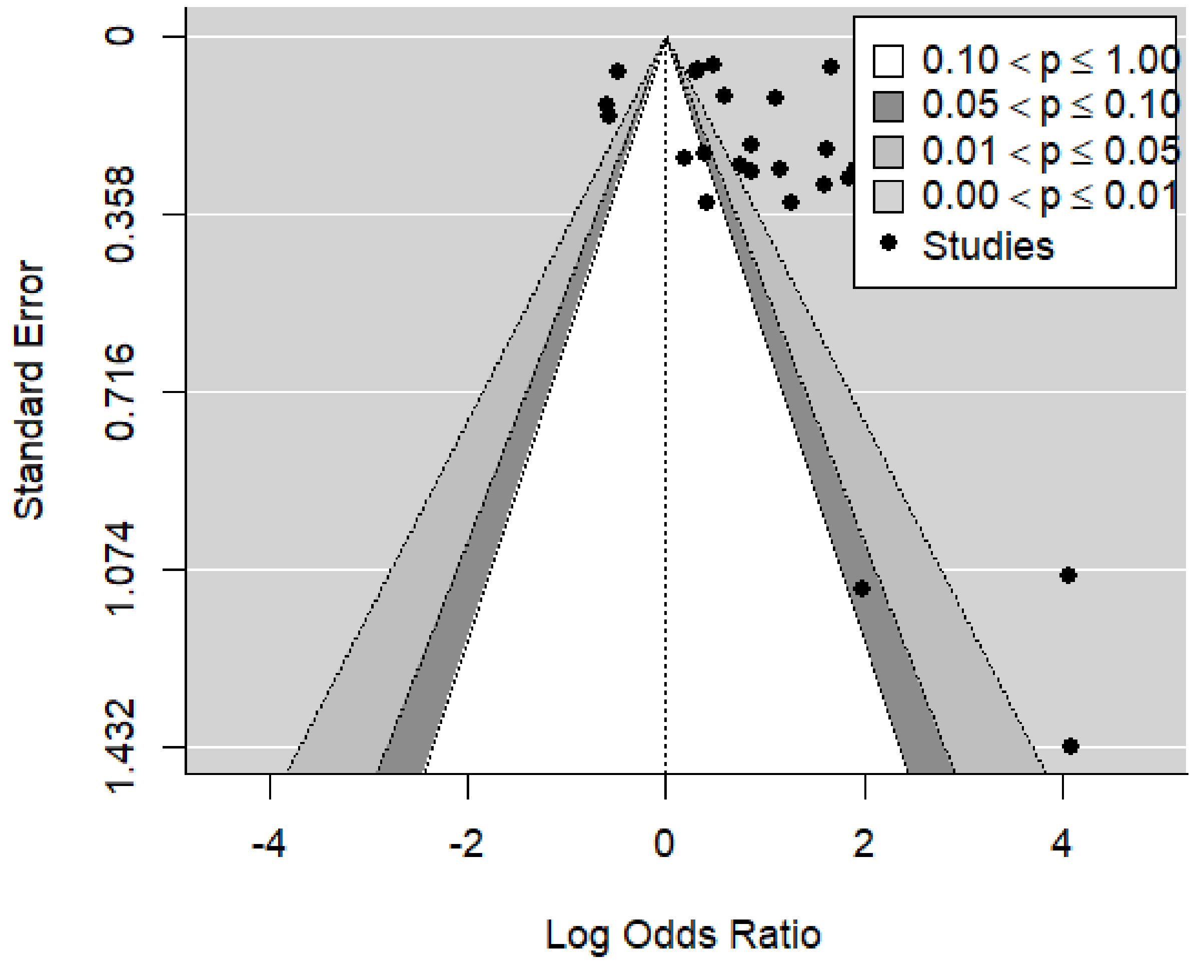


Figure 18: Contoured Funnel Plot

Discussion

Summary of Findings

At all levels of adjustment, these results indicate that nudging is significant for promoting hand hygiene, with only 6 of 34 effect sizes indicating a null or negative effect. That said, the measures of heterogeneity suggest more nuanced context-related analysis may be necessary for the determination of optimal nudge-context matching. Interestingly, the two studies that included negative effect sizes *also* included positive effect sizes with different interventions. Given that these took place in environments with a single population (schools and a military base for Naluonde, et al, and Wiik, respectively), it's plausible that the effect was attenuated by an adaptive effect: as the nudge become familiar, it merged into the background and diminished in effectiveness. This however, is speculative, and is not found in other studies with constant populations. Of considerable concern are the Egger's test results and the RVE estimates. Given these values, the diversity of contexts and populations, and the fact that at least one of the studies was associated with a corporately sponsored experiment testing the efficacy of a nudge-related product, there is a very real possibility of publication bias skewing the results. More research is warranted with respect to 1) the durability of the nudge over time within a fixed population; 2) comparative analysis of the specific nudge-types; and 3) the place- and population-related distinctions that define contextual applicability.

As mentioned above, five studies were identified that met inclusion criteria, but were not amenable to summary analysis. These studies also found positive results from nudging, and are summarized in Table 3 below:

Limitations

As a thesis submitted as a component of curricular requirements for a graduate program in public health, it was necessary to make certain departures from professional guidelines in the performance of a meta-analysis. For example, interrater reliability is a generally recommended metric during phases of literature search and paper-selection[80]. This, however, would have required the inclusion of additional research collaborators, and would have violated the integrity of the thesis as an original, independent piece of research. Similarly, the engagement of a research librarian to assist in search comprehensiveness was – though normally recommended – outside the scope of permissions for the assignment.

As a further consideration with respect to methodology, much of the work completed for the thesis was work that coincided with homework assignments in the PHPH 8890: Special Topics in Biostatistics—Meta-Analysis course at Georgia State University. As such, mechanisms for publication integrity—for example, pre-registration of the SRMA with a professional institution – were also not completed. As such, the document in its present iteration should be considered suitable only as a curricular assignment, not as a formal academic document ready for publication.

In terms of external validity, several important factors exceed the scope of this project.

- Firstly, the focus of the paper – nudging – constitutes a broad array of interventional techniques. While other research has performed stratifications on the efficacy of nudges by *types of nudge*, this paper did not do so. Further research exploring whether a given nudge is superior to alternatives is warranted.
- Relatedly, the studies included took place in multiple settings and with diverse populations. It is not, for example, obviously free of bias to infer that variation in this sense has no bearing on outcome. For example, it is not obvious that children in the context of a school are reasonably

comparable to healthcare professionals in a treatment ward. Factors like education, professional obligation, seriousness of or punitive consequences accompanying non-compliance, maturity, and personality may carry significant implications for the efficacy and appropriateness of an intervention.

- Finally, the breadth of broader social, economic, and cultural contexts may also have implications respecting generalizability. What works in a primary school in Bangladesh may reasonably be held to not work in a nursing home in Denmark. However, the dearth of studies performed in more explicitly comparable socio-economic contexts would have precluded the SRMA being performed, had this paper stipulated such as a criterion for inclusion.

Author(s) Country Year	Setting/Design	Intervention(s)/Nudge-Type	Duration	Sample Size: N=	Outcome Measured	Quantitative Summary:
The following studies were not included in the meta-analysis, despite having met criteria for inclusion, as they did not report sufficient detail to reconstruct counts/odds ratios:						
Caris, et al, 2018, The Netherlands[123]	**In a university hospital, healthcare staff were measured before-and-after for frequency of hand-sanitizing at key hygiene moments, with nudges being later deployed in the form of sign-reminders.**	**Salience.**	**6 Weeks**	**Unclear**	**Number of times a hand-sanitizing dispenser was used.**	**From the paper: "The six dispensers together were used 2842 times. Both posters increased the overall use of the entrance dispenser on ward B [poster 1: relative risk: 1.61 (95% confidence interval: 1.18–2.20), poster 2: 1.72 (1.17–2.53)] but not of the entrance dispenser on ward A [poster 1: 1.04 (0.79–1.38), poster 2: 1.07 (0.80–1.42)]."**
Stangerup, et al, 2020, Denmark[124]	**In an Orthopedic Surgery Ward, healthcare workers were counted sanitizing their hands after potentially contaminating events, before and after the introduction of an electronic reminder system.**	**Salience**	**4.5 Months**	**84**	**Proportion of times contaminating events were met with hand sanitizer use.**	**Baseline_Doctors: 30% Intervention_Doctors: 55% Baseline_Nurses: 42% Intervention_Nurses: 61%**
Štefančič & Jevšnik, 2020,	**Food preparation workers in a nursing home were measured on a variety of hygiene-related practices (including but not limited**	**Salience Framing Loss Aversion**	**6 Months**	**12**	**Proportion of times best practices recommended a hygienic practice**	**Unclear -- there are multiple metrics reported making individual practice disentanglement challenging.**

Slovenia[125]	to hand-hygiene) for a baseline interval, then over 4 intervals with varying nudges				that was followed by such a practice.	
Stirapongsasuti, et al, 2021, Japan[126]	In two corporate settings, social robot interactions were used to encourage hand sanitizer use during the COVID-19 pandemic, across 3 intervention levels (baseline, floor arrows only, robot interaction, and personalized robot interaction).	Salience	6 Days	50	Number of times a hand-sanitizing dispenser was used.	In a before-and-after model, total number of times used: Baseline_Group_1: 4 Intervention_1_G1: 9 Intervention_2_G1: 22 Intervention_3_G1: 42 Baseline_Group_2: 15 Intervention_1_G2: 16 Intervention_2_G2: 70 Intervention_3_G2: 90
Watson, et al, 2019 Iraq[127]	In an Iraqi refugee camp, children were given clear bars of soap that had a toy embedded within it. Measures were taken key hand hygiene moments where hands were washed, before soap distribution and after.	Unclear	1 month	Unclear	Proportion of times handwashing events were met with handwashing.	Baseline: 24% Intervention: 40%

Table 3: Studies Not Included in Statistical Analysis

Conclusion

Hand hygiene – despite its nearly universal accessibility in developed countries, its comparative cheapness, and its uncontroversial nature – remains an under-practiced mechanism for improving public health. In domains as varied as schools, hospitals, and restaurants, hand hygiene compliance and observation of best practices would provide significant benefits with respect to virtually all aspects of infectious disease control. However, hand hygiene is behavioral, and thus not amenable to centralized or top-down implementation methods. Nudges – cheap, easily implemented modifications to choice environments – appear to significantly improve hand hygiene compliance in a variety of socio-cultural contexts and across a variety of population demographics. Further research may shed light on precisely the types of nudges that are most effective for a given population, as well as clarifying the extent of and causes underlying publication bias in this field.

Appendix 1

Relevant Excluded Studies

The following studies were not included because they were – at the time of writing – incomplete and/or unpublished.

Makata K, Kinung'hi S, Hansen C, et al. Hand hygiene intervention to optimize helminth infection control: Design and baseline results of Mikono Safi–An ongoing school-based cluster-randomised controlled trial in NW Tanzania. Chenette E, ed. *PLOS ONE*. 2020;15(12):e0242240. doi:10.1371/journal.pone.0242240

The Effect of Behaviour Change Interventions on Use of Public Handwashing Stations in Bangladesh - Full Text View - ClinicalTrials.gov. Clinicaltrials.gov. Published 2021. Accessed April 10, 2022. https://clinicaltrials.gov/ct2/show/NCT04765540

Mugambe RK, Mselle JS, Ssekamatte T, et al. Impact of mhealth messages and environmental cues on hand hygiene practice among healthcare workers in the greater Kampala metropolitan area, Uganda: study protocol for a cluster randomized trial. *BMC Health Services Research*. 2021;21(1). doi:10.1186/s12913-021-06082-3

The following studies (Takebayashi. Blackwell, and Dassen) were excluded on the basis of incompatible outcome measure (volume, in ml, of hand sanitizer dispensed). In addition to being incompatible with the other studies (given their different focus on outcome measure), these studies were deemed to be more methodologically suspect, as the outcome could be gamed by accidents or repetitious but superfluous use. That said, all three studies showed moderate—but consistent – increases in volume of hand disinfectant/soap used following the implementation of the nudges.

Blackwell, C., Goya-Tocchetto, D., & Sturman, Z. (2017). Nudges in the restroom: how hand-washing can be impacted by environmental cues. *Available at SSRN 3007866*.

Dassen, L. (2021). *Clean your hands please!: Using nudging to improve hand hygiene amongst Dutch citizens during COVID-19* (Bachelor's thesis, University of Twente).

Takebayashi, M., & Takebayashi, K. (2021). Control experiment for health center users to compare the usage of hand sanitizers through nudges during the COVID-19 pandemic in Japan. *International Research Journal of Public and Environmental Health*, *8*(6), 299-303.

Huang was excluded on the basis of using an organizational-level model – all reported effects were reported at the level of schools, not at the level of individuals and their behavior. As a multi-level project, the study likely produced usable data, but it was not reported and could not be located online.

Huang, H. C., Le, N., Battle, M., Villasenor, J. M., & Maule, L. (2021). Nudging Handwashing among Primary School Students in the Philippines: Evidence from a Cluster Randomized Trial. *The American journal of tropical medicine and hygiene*, *105*(6), 1806-1815.

Appendix 2

Abstract and Title Screening Tool

a. Tool:
   i. Does the title or abstract:
      1. 1_Indicate the use of English?
         Yes = Continue; No = Discard.
      2. 2_ Indicate any evidence of having been retracted?
         Yes = Discard; No = Continue. Unclear = Full-Text Review
      3. 2_Indicate publication after 1995?
         Yes = Continue; No = Discard.
      4. 3_Indicate the explicit use of a Nudge or the use of Nudge Theory as a theoretical framework?
         Yes = Continue; No = Discard. Unclear = Full-Text Review
      5. 4_Indicate the paper analyzes a health-related outcome?
         Yes = Continue; No = Discard.
      6. 5_Indicate the use of or reference of experimental or quasi-experimental procedures?
         Yes = Continue; No = Discard; Unclear = Full-Text Review
      7. 6_Indicate the collection of a quantitative metric or design?
         Yes = Continue; No = Discard; Unclear = Full-Text Review

b. Rationale, respectively:
   1. I simply don't have the linguistic breadth or capability to discern the usefulness of foreign-language studies.
   2. The modern "Nudge" theory did not become defined prior to 1995; truthfully, the popularization of the idea followed the 2008 book by Sunstein and Thaler, so there will doubtfully be any studies prior to that.
   3. Making reference to *any* behavioral intervention (or to the related concepts of "Sludge" or "Boost") will likely make reference to the Nudge theory, but won't be admissible for the assessment of the efficacy of nudge interventions.
   4. Nudges are frequently applied to spheres of marketing, finance, economics, policy, and so forth, and those studies may also include otherwise relevant components (quantitative, nudges, experimental, and etc.). These need to be removed to keep the emphasis upon applications to public health and preventative health behaviors.
   5. Discerning efficacy – as opposed to propositions or discussions of policy implications, theoretical underpinnings, and so on – requires some kind of trial; associational studies may be useful, but given the substandard quality of evidence, if a sufficient number of studies using exp. or quasi-exp. designs can be found, that would be preferable.
   6. Quantitative results are required for the meta-analysis component of the review.

Appendix 3

Data Extraction Codebook

1) What as the nudge intended to promote the outcome of hand-washing, sanitizing, or otherwise hand-hygiene?
    a. Yes
    b. No/Unclear = STOP
2) Were study participants:
    a. Divided into intervention/control groups?
        i. How are the comparison or control groups formed?
            1. Random Assignment or Process?
            2. Other (STOP)
        ii. Specify RCT Design:
            1. Simple Random Assignment
            2. Systematic Random Assignment
            3. Stratified/Blocked
            4. Yoked Pairs
            5. Matched Pairs
            6. Cluster Randomized Assignment
            7. Other (SPECIFY)
            8. Unclear
        iii. Who performed group assignment?
            1. Research Staff
            2. Program Staff/Professional Staff
            3. Other (SPECIFY)
            4. Unclear
        iv. How was random assignment performed?
            1. Computer Generated
            2. Random Numbers Table
            3. Coins or Dice
            4. Envelopes
            5. Other (SPECIFY)
            6. Unclear
    b. A single group in a before/after or repeated measures study?
    c. Neither (STOP)
3) Dates
    a. Input start and end dates of the study
4) Funding
    a. Please list all sources of funding or potential conflicts of interest, to the highest level of available specificity
5) Settings
    a. Where was the study performed?
        i. Retail Environment
        ii. Clinical Environment

iii. Food Preparation Environment
iv. School Environment
v. Home Environment
vi. Workplace Environment
vii. Public Space
viii. Digital Environment

b. How many separate treatment sites/environments were included?
c. Were there implementation differences across sites?
    i. Yes (DESCRIBE)
    ii. No
        1. Explicitly Stated?
        2. Inferred From Description?
    iii. Unclear
d. In what city, state, country did the study take place?

6) Is there specification of the nudge intervention adhering to the standard nudge definition?
    a. Non-Coercive?
    b. Economically Insignificant?
    c. Easily and Cheaply Avoided?
    d. Easily and Cheaply Ignored?
    e. Other (Specify)
    f. No (STOP)
7) Through what media was the nudge implemented:
    a. Physical Environment Modification
    b. Signage or Ambient Stimuli
    c. Mobile Device
    d. Email
    e. Snail-Mail
    f. Television
    g. Other (for example, auto-enrollment)
8) What type of Nudge was implemented?
    a. Default or Opt-Out
    b. Reminder
    c. Negativity Bias or Framing
    d. Physical Environment Modification
    e. Ease Enhancement
    f. Informational Media
    g. Recommendation
    h. Social Desirability or Responsibility
    i. Salience Modification
    j. Decision Protocol
9) Demographic Characteristics (if included):
    a. N =

b. %Male
c. Race/Ethnicity:

            i. %White
            ii. %Black
            iii. %AIAN
            iv. %Hispanic
            v. %Other
    d. Socioeconomic Status
    e. Age of Participants:
            i. % <30
            ii. % 30-50
            iii. % 50+

10) Were there significant differences between the intervention and control groups at baseline?
    a. Yes (DESCRIBE)
    b. No
    c. Unclear
11) What type of Effect Size measure was collected?
    a. Mean Difference (e.g., Cohen's D)
    b. Odds Ratio
    c. Correlation Coefficient (e.g., Pearson's *r*)
    d. Other (SPECIFY)

Appendix 4

R code and Extracted Data Table

Study	StudyID	OutcomeI	Trt_N	Ct_Trt_Po	Ct_Trt_Ne	Ctrl_N	Ct_Ctrl_Po	Ct_Ctrl_Ne	OR	95%CI_lov	95%CI_hig	OR.logged	V.Or.logge
Aarestrup,	1	101	30	20	10	30	1	29	58	6.8712	489.5806	4.0604	1.1845
	1	102	30	6	24	30	1	29	7.25	0.8155	64.4572	1.981	1.2428
Deshmukh	2	103	521	341	180	92	20	72	6.82	4.0252	11.5553	1.9199	0.0724
Dreibelbis,	3	104	158	108	50	145	26	119	9.8862	9.76	16.98	2.291	0.076
	3	105	119	69	50	145	26	119	6.1362	3.6113	11.047	1.8431	0.0814
Grover, et	4	106	851	460	391	431	121	310	3.0141	2.3483	3.8687	1.1033	0.0162
	4	107	861	542	319	254	43	211	8.3372	5.8405	11.9012	2.1207	0.033
Hansen, et	5	108	2580	35	2545	5316	23	5293	3.4348	2.0251	5.8258	1.234	0.0727
	5	109	3242	33	3209	5316	23	5293	2.3666	1.3872	4.0375	0.8614	0.0743
	5	110	2982	351	2631	5316	23	5293	30.7016	20.083	46.9346	3.4243	0.0469
	5	111	5320	115	5205	5316	23	5293	5.0845	3.2443	7.9687	1.6262	0.0526
	5	112	3530	566	2964	5316	23	5293	43.9453	28.8938	66.8375	3.7829	0.0458
	5	113	5101	317	4784	5316	23	5293	15.249	9.9689	23.3259	2.7245	0.047
	5	114	4005	505	3500	5316	23	5293	33.2045	21.8156	50.539	3.5027	0.0459
	5	115	5331	1048	4283	5316	23	5293	56.3102	37.1802	85.2831	4.0309	0.0449
	5	116	4295	600	3695	5316	23	5293	37.3689	24.5887	56.7919	3.6208	0.0456
King, et al,	6	117	160	75	85	120	18	102	5	2.7731	9.0153	1.6094	0.0905
	6	118	124	26	98	120	18	102	1.5034	0.7756	2.9141	0.4077	0.114
Mlakar, et	7	119	585	410	175	675	380	295	1.8188	1.4403	2.2968	0.5982	0.0142
Mobekk ar	8	120	100	46	54	100	7	93	11.3175	4.7749	26.8248	2.4263	0.1939
	8	121	100	40	60	100	7	93	8.8571	3.7252	21.0591	2.1812	0.1953
Naluonde,	9	122	1608	691	917	1664	594	1070	1.3574	1.1792	1.5625	0.3056	0.0052
	9	123	2346	1664	682	2949	1767	1182	1.6321	1.4539	1.8321	0.4899	0.0035
	9	124	1242	772	470	2962	2151	811	0.6193	0.5383	0.7125	-0.4792	0.0051
	9	125	1608	62	1546	1664	109	1555	0.5721	0.4156	0.7876	-0.5584	0.0266
	9	126	2353	1246	1107	2949	518	2431	5.2823	4.6631	5.9839	1.6644	0.004
	9	127	1242	567	675	2962	1110	1852	1.4015	1.2255	1.6028	0.3376	0.0047
Palinko, et al, 2021	10	128	152	102	50	211	97	114	2.3975	1.5544	3.698	0.8744	0.0489
Pfattheicher, et al, 2018	11	129	210	175	35	148	104	44	2.1154	1.2755	3.5084	0.7492	0.0666
Weijers ar	12	130	167	71	96	138	46	92	1.3476	0.8855	2.0507	0.2983	0.0459
	12	131	146	55	91	138	46	92	1.2088	0.7426	1.9675	0.1896	0.0618
Wichaidit,	13	132	223	24	199	243	0	243	29.3065	3.9301	218.5353	3.3778	1.0508
Wilk, 2019	14	133	413	401	12	439	397	42	3.5353	1.8338	6.8153	1.2628	0.1122
	14	134	412	156	256	437	228	209	0.5586	0.4249	0.7344	-0.5823	0.0195

Thesis_FINAL-model.R

goffm

2022-04-13

```
#The code used herein was built around/implemented via modifications from the
resources provided by Dr. Terri Pigott,
#of Georiga State University, and the documentation for the packages mentione
d below.

library(metafor)

## Loading required package: Matrix

##
## Loading the 'metafor' package (version 3.0-2). For an
## introduction to the package please type: help(metafor)

library(clubSandwich)

## Warning: package 'clubSandwich' was built under R version 4.1.3

## Registered S3 method overwritten by 'clubSandwich':
##   method    from
##   bread.mlm sandwich

setwd("C:/Users/goffm/OneDrive/Documents/R")
#As discussed in the methods section, this analysis is built upon the "metafo
r" and "clubSandwich" R packages.

Nudge <- readxl::read_xlsx("Thesis_FX.xlsx")

str(Nudge)

## tibble [34 x 14] (S3: tbl_df/tbl/data.frame)
##  $ Study      : chr [1:34] "Aarestrup, et al, 2016" NA "Deshmukh, et al, 2
019" "Dreibelbis, et al, 2016" ...
##  $ StudyID    : num [1:34] 1 1 2 3 3 4 4 5 5 5 ...
##  $ OutcomeID  : num [1:34] 101 102 103 104 105 106 107 108 109 110 ...
##  $ Trt_N      : num [1:34] 30 30 521 158 119 ...
##  $ Ct_Trt_Pos : num [1:34] 20 6 341 108 69 460 542 35 33 351 ...
##  $ Ct_Trt_Neg : num [1:34] 10 24 180 50 50 ...
##  $ Ctrl_N     : num [1:34] 30 30 92 145 145 ...
##  $ Ct_Ctrl_Pos: num [1:34] 1 1 20 26 26 121 43 23 23 23 ...
##  $ Ct_Ctrl_Neg: num [1:34] 29 29 72 119 119 ...
##  $ OR         : num [1:34] 58 7.25 6.82 9.89 6.14 ...
##  $ 95%CI_low  : num [1:34] 6.871 0.816 4.025 9.76 3.611 ...
```

```
##  $ 95%CI_high : num [1:34] 489.6 64.5 11.6 17 11 ...
##  $ OR.logged  : num [1:34] 4.06 1.98 1.92 2.29 1.84 ...
##  $ V.Or.logged: num [1:34] 1.1845 1.2428 0.0724 0.076 0.0814 ...

table(Nudge$Study)

##
##      Aarestrup, et al, 2016       Deshmukh, et al, 2019
##                           1                           1
##     Dreibelbis, et al, 2016         Grover, et al, 2018
##                           1                           1
##         Hansen, et al, 2021           King, et al, 2016
##                           1                           1
##         Mlakar, et al, 2107     Mobekk and Stokke, 2020
##                           1                           1
##       Naluonde, et al, 2019        Palinko, et al, 2021
##                           1                           1
##   Pfattheicher, et al, 2018 Weijers and de Koning, 2020
##                           1                           1
##      Wichaidit, et al, 2020                  Wiik, 2019
##                           1                           1

#Effect Size Calculator
#The code below calculates the Log Odds Ratio using the sample N and the coun
t of events.
#Then it assigns the output to variables named "lor" (log odds ratio) and "Va
rlor" (variance).

Nudge <- escalc(measure = "OR",
                ai = Ct_Trt_Pos, n1i = Trt_N,
                ci = Ct_Ctrl_Pos, n2i = Ctrl_N,
                data = Nudge,
                var.names = c("lor", "varlor"))


summary(Nudge$lor)

##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## -0.5823  0.5170  1.6178  1.6472  2.3925  4.0911

#Standard Random Effects Model

Nudge_re <- rma(yi = lor,
                vi = varlor,
                data = Nudge,
                method = "REML")

summary(Nudge_re)

##
## Random-Effects Model (k = 34; tau^2 estimator: REML)
```

```
##
##   logLik  deviance       AIC       BIC      AICc
## -57.1419  114.2838  118.2838  121.2768  118.6838
##
## tau^2 (estimated amount of total heterogeneity): 1.7063 (SE = 0.4477)
## tau (square root of estimated tau^2 value):      1.3063
## I^2 (total heterogeneity / total variability):   98.77%
## H^2 (total variability / sampling variability):  81.09
##
## Test for Heterogeneity:
## Q(df = 33) = 1972.0138, p-val < .0001
##
## Model Results:
##
## estimate      se    zval    pval   ci.lb   ci.ub
##   1.5664  0.2322  6.7448  <.0001  1.1113  2.0216  ***
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#Multivariate Effect Size Model + Imputed Covariance Matrix + RVE

V_list <- impute_covariance_matrix(vi = Nudge$varlor,
                                   cluster = Nudge$StudyID,
                                   r = .80)

NudgeSub2 <- rma.mv(yi = lor,
                    V = V_list,
                    random = ~1 | StudyID/OutcomeID,
                    data = Nudge,
                    method = "REML")

summary(NudgeSub2)
```

```
##
## Multivariate Meta-Analysis Model (k = 34; method: REML)
##
##   logLik  Deviance       AIC       BIC      AICc
## -52.2552  104.5105  110.5105  115.0000  111.3381
##
## Variance Components:
##
##             estim    sqrt  nlvls  fixed             factor
## sigma^2.1  0.6099  0.7809     14     no            StudyID
## sigma^2.2  0.9043  0.9509     34     no  StudyID/OutcomeID
##
## Test for Heterogeneity:
## Q(df = 33) = 4616.9043, p-val < .0001
##
## Model Results:
```

```
##
## estimate      se     zval     pval    ci.lb    ci.ub
##   1.4161  0.2987  4.7415  <.0001  0.8307  2.0015   ***
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
NudCef <- coef_test(NudgeSub2,
                    cluster = Nudge$StudyID,
                    vcov = "CR2")

NudCef
```

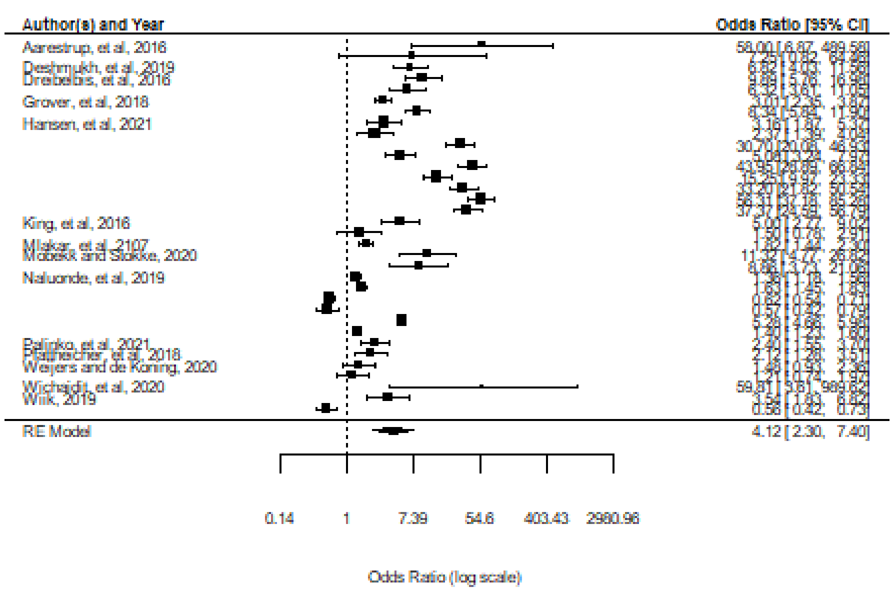
```
##    Coef. Estimate    SE t-stat d.f. (Satt) p-val (Satt) Sig.
##  intrcpt     1.42 0.301   4.71        11.5       <0.001  ***
```

```
predict(NudgeSub2)
```

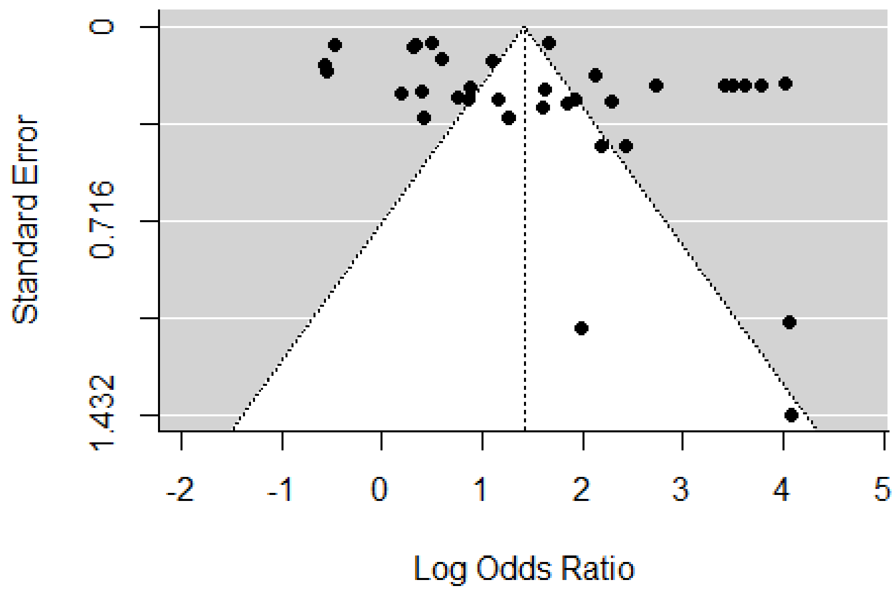
```
##
##    pred     se  ci.lb  ci.ub   pi.lb  pi.ub
##  1.4161 0.2987 0.8307 2.0015 -1.0657 3.8979
```

```
#Forest Plot and Traditional Funnel Plot:

forest(NudgeSub2, slab = Nudge$Study, cex=.5, atransf= exp, header="Author(s)
and Year")
```



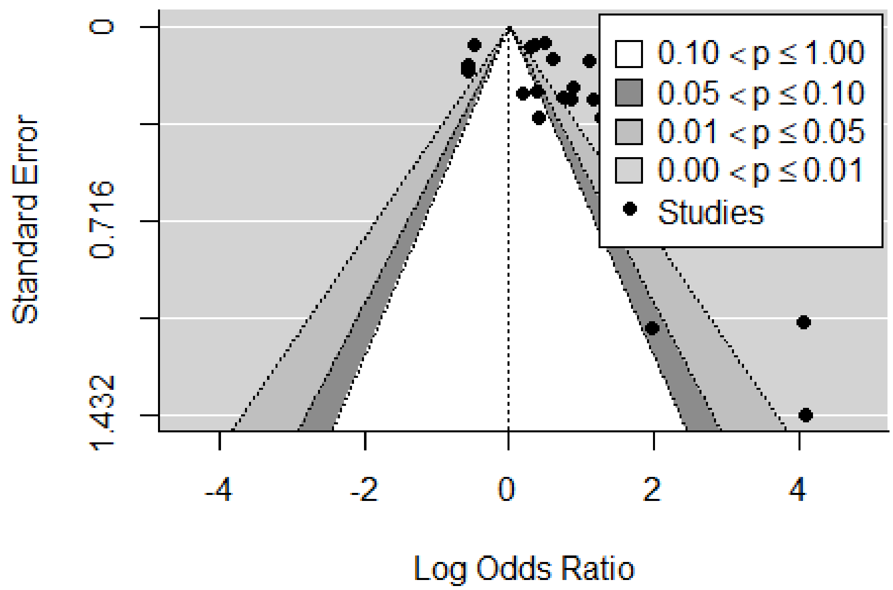

```
funnel(NudgeSub2)
```




```
#Coutoured Funnel Plot:


IndepRE_Nudge <- rma(yi = lor,
               vi = varlor,
               data = Nudge,
               method = "REML")


funnel(IndepRE_Nudge,
       level=c(90, 95, 99),
       shade=c("white","gray55","gray75"),
       refline = 0,
       legend=TRUE)
```




```
#Egger's Sandwich


Nudge$Tot_N = Nudge$Trt_N + Nudge$Ctrl_N


eggers <- rma.mv(yi = lor,
                 V = V_list,
                 mods = ~ Tot_N,
                 random = ~1 | StudyID/OutcomeID,
                 data = Nudge,
                 method = "REML")

summary(eggers)

##
## Multivariate Meta-Analysis Model (k = 34; method: REML)
##
##    logLik   Deviance        AIC        BIC       AICc
## -49.4594    98.9187   106.9187   112.7817   108.4002
##
## Variance Components:
##
##              estim    sqrt  nlvls  fixed             factor
## sigma^2.1   0.5539  0.7442     14     no            StudyID
## sigma^2.2   0.8537  0.9240     34     no  StudyID/OutcomeID
##
```

```
## Test for Residual Heterogeneity:
## QE(df = 32) = 3584.6135, p-val < .0001
##
## Test of Moderators (coefficient 2):
## QM(df = 1) = 2.4087, p-val = 0.1207
##
## Model Results:
##
##          estimate      se    zval    pval    ci.lb   ci.ub
## intrcpt    1.1244  0.3419  3.2882  0.0010   0.4542  1.7945  **
## Tot_N      0.0001  0.0001  1.5520  0.1207  -0.0000  0.0003
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#Using clubSandwich to get the RVE estimate for the Egger's sandwich test

eggerscef <- coef_test(eggers,
                       cluster=Nudge$StudyID,
                       vcov = "CR2")
eggerscef
```

```
##    Coef. Estimate       SE t-stat d.f. (Satt) p-val (Satt) Sig.
##  intrcpt 1.124350 0.321118   3.50       11.44      0.00468   **
##    Tot_N 0.000141 0.000106   1.33        1.52      0.34939
```

References

[1] Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. Journal of Statistical
[2] James Pustejovsky (2022). clubSandwich: Cluster-Robust (Sandwich) Variance Estimators with Small-Sample Corrections. R package version 0.5.5. https://CRAN.R-project.org/package=clubSandwich
[3] Pustejovsky, J. E., & Tipton, E. (2021). Meta-analysis with Robust Variance Estimation: Expanding the Range of Working Models. *Prevention Science*. https://doi.org/10.1007/s11121-021-01246-3
[4] Thesis, Capstone & Dissertation. School of Public Health. Published 2017. Accessed April 10, 2022. https://publichealth.gsu.edu/graduate-student-resources/thesis-capstone-dissertation/
[5] Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an Updated Guideline for Reporting Systematic Reviews. *British Medical Journal*. 2021;372(71):n71. doi:10.1136/bmj.n71
[6] Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (editors). *Cochrane Handbook for Systematic Reviews of Interventions* version 6.3 (updated February 2022). Cochrane, 2022. Available from www.training.cochrane.org/handbook.
[7]Broers VJV, De Breucker C, Van den Broucke S, Luminet O. A systematic review and meta-analysis of the effectiveness of nudging to increase fruit and vegetable choice. *European Journal of Public Health*. 2017;27(5):912-920. doi:10.1093/eurpub/ckx085
[8] LaTeX - A document preparation system. Latex-project.org. Published 2022. Accessed April 10, 2022. https://www.latex-project.org/
[9] United States: child mortality rate 1800-2020 | Statista. Statista. Published 2020. Accessed April 10, 2022. https://www.statista.com/statistics/1041693/united-states-all-time-child-mortality-rate/
[10] Leading Causes of Death in 1900. Illinois.edu. Published 2022. Accessed April 10, 2022. https://cdn.citl.illinois.edu/courses/KIN122/week1/chapter1/web_data/file16.htm
[11] QuickStats: Number of Deaths from 10 Leading Causes — National Vital Statistics System, United States, 2010. Published 2022. Accessed April 10, 2022. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6208a8.htm#:~:text=In%202010%2C%20a%20total%20of,nearly%2050%25%20of%20all%20deaths.
[12] Mathews TJ, MacDorman MF. Infant mortality statistics from the 2010 period linked birth/infant death data set. National vital statistics reports; vol 62 no 8. Hyattsville, MD: National Center for Health Statistics. 2013.
[13] About Diphtheria. Published 2022. Accessed April 10, 2022. https://www.cdc.gov/diphtheria/about/index.html#:~:text=Due%20to%20the%20success%20of,outbreaks%20reported%20in%20recent%20years.
[14] CDCTB. Data & Statistics. Centers for Disease Control and Prevention. Published March 24, 2022. Accessed April 10, 2022. https://www.cdc.gov/tb/statistics/default.htm
[15] Wharton PPI. Penn Wharton Budget Model. Penn Wharton Budget Model. Published June 27, 2016. Accessed April 10, 2022. https://budgetmodel.wharton.upenn.edu/issues/2016/1/25/mortality-in-the-united-states-past-present-and-future
[16] Haque M, Sartelli M, McKimm J, Abu Bakar MB. Health care-associated infections – an overview. *Infection and Drug Resistance*. 2018;Volume 11:2321-2333. doi:10.2147/idr.s177247
[17] CDC. About Antibiotic Resistance. Centers for Disease Control and Prevention. Published March 15, 2022. Accessed April 10, 2022. https://www.cdc.gov/drugresistance/about.html#:~:text=Antibiotic%20resistance%20happens%20when%20germs,in%20the%20U.S.%20each%20year.

[18] Montmany, Sandra, et al. "Preventable deaths and potentially preventable deaths. What are our errors?." *Injury* 47.3 (2016): 669-673.
[19] Anand, Sudhir, and Kara Hanson. "Disability-adjusted life years: a critical review." *Journal of health economics* 16.6 (1997): 685-702.
[20] Gardner, John W., and Jill S. Sanborn. "Years of potential life lost (YPLL)—what does it measure?." *Epidemiology* (1990): 322-329.
[21] FastStats - Leading Causes of Death. Published 2022. Accessed April 10, 2022. https://www.cdc.gov/nchs/fastats/leading-causes-of-death.htm
[22] Fedak KM, Bernal A, Capshaw ZA, Gross S. Applying the Bradford Hill criteria in the 21st century: how data integration has changed causal inference in molecular epidemiology. *Emerg Themes Epidemiol*. 2015;12:14. Published 2015 Sep 30. doi:10.1186/s12982-015-0037-4
[23] Mokdad AH, Marks JS, Stroup DF, Gerberding JL. Actual causes of death in the United States, 2000 [published correction appears in JAMA. 2005 Jan 19;293(3):298] [published correction appears in JAMA. 2005 Jan 19;293(3):293-4]. *JAMA*. 2004;291(10):1238-1245. doi:10.1001/jama.291.10.1238
[24] Guwande, A. (2010). The checklist manifesto. *New York: Picadur*.
[25] Haynes, A. B., Weiser, T. G., Berry, W. R., Lipsitz, S. R., Breizat, A. H. S., Dellinger, E. P., ... & Gawande, A. A. (2009). A surgical safety checklist to reduce morbidity and mortality in a global population. *New England journal of medicine*, *360*(5), 491-499
[26] Milgram, S. (1963). Behavioral study of obedience. Journal of Abnormal and Social Psychology, 67. 37 1-378.
[27] Kahneman, D., & Tversky, A. (2013). Choices, values, and frames. In *Handbook of the fundamentals of financial decision making: Part I* (pp. 269-278).
[28] Milkman, K. (2021). *How to Change: The Science of Getting from where You are to where You Want to be*. Penguin.
[29] Ariely, D., & Jones, S. (2008). *Predictably irrational* (pp. 278-9). New York: HarperCollins.
[30] Whitley Jr, B. E., & Kite, M. E. (2012). *Principles of research in behavioral science*. Routledge.
[31] Wilk J. Mind, Nature and the Emerging Science of Change: An Introduction to Metamorphology. *Metadebates on Science*. Published online 1999:71-87. doi:10.1007/978-94-017-2245-2_6
[32] Thaler, R. H., & Sunstein, C. R. Nudge: Improving decisions about health, wealth, and happiness.
[33] Krulwich R. There's A Fly In My Urinal. NPR.org. Published December 19, 2009. Accessed April 10, 2022. https://www.npr.org/templates/story/story.php?storyId=121310977
[34] Korobkin, R. (1997). Status quo bias and contract default rules. *Cornell L. Rev.*, *83*, 608.
[35] Whyte, K. P., Selinger, E., Caplan, A. L., & Sadowski, J. (2012). Nudge, nudge or shove, shove—the right way for nudges to increase the supply of donated cadaver organs. *The American Journal of Bioethics*, *12*(2), 32-39.
[36] Bovens, Luc. "The ethics of nudge." *Preference change*. Springer, Dordrecht, 2009. 207-219.
[37] Lavi, M. (2018). Evil nudges. *Vand. J. Ent. & Tech. L.*, *21*, 1.
[38] Will A New Georgia Law Restrict Voter Access Or Restore Faith In Elections? : The NPR Politics Podcast. NPR.org. Published March 29, 2021. Accessed April 10, 2022. https://www.npr.org/transcripts/982439178
[39] Hertwig, R., & Grüne-Yanoff, T. (2017). Nudging and boosting: Steering or empowering good decisions. *Perspectives on Psychological Science*, *12*(6), 973-986.
[40] Selinger, E., & Whyte, K. (2011). Is there a right way to nudge? The practice and ethics of choice architecture. *Sociology Compass*, *5*(10), 923-935.
[41] de Ridder D, Kroese F, van Gestel L. Nudgeability: Mapping Conditions of Susceptibility to Nudge Influence. *Perspectives on Psychological Science*. Published online August 23, 2021:174569162199518. doi:10.1177/1745691621995183

[42] Taube, O., & Vetter, M. (2019). How green defaults promote environmentally friendly decisions: Attitude-conditional default acceptance but attitude-unconditional effects on actual choices. *Journal of Applied Social Psychology*, *49*(11), 721-732.
[43] Smith PJ, Chu SY, Barker LE. Children Who Have Received No Vaccines: Who Are They and Where Do They Live? *Pediatrics*. 2004;114(1):187-195. doi:10.1542/peds.114.1.187
[44] Kahane LH. Politicizing the Mask: Political, Economic and Demographic Factors Affecting Mask Wearing Behavior in the USA. *Eastern Economic Journal*. 2021;47(2):163-183. doi:10.1057/s41302-020-00186-0
[45] Clear, J. (2018). *Atomic habits: An easy & proven way to build good habits & break bad ones*. Penguin.
[46] Oakes, A. H., & Patel, M. S. (2020). A nudge towards increased experimentation to more rapidly improve healthcare. *BMJ quality & safety*, *29*(3), 179-181.
[47] Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.
[48] Byrne, M. D., & Bovair, S. (1997). A working memory model of a common procedural error. *Cognitive science*, *21*(1), 31-61.
[49] Eyal, N. (2014). *Hooked: How to build habit-forming products*. Penguin.
[50] Van Gestel, L. C., Kroese, F. M., & De Ridder, D. T. D. (2018). Nudging at the checkout counter–A longitudinal study of the effect of a food repositioning nudge on healthy food choice. *Psychology & health*, *33*(6), 800-809.
[51] Grimm, P. (2010). Social desirability bias. *Wiley international encyclopedia of marketing*.
[52] Nettle, D., Harper, Z., Kidson, A., Stone, R., Penton-Voak, I. S., & Bateson, M. (2013). The watching eyes effect in the Dictator Game: it's not how much you give, it's being seen to give something. *Evolution and Human Behavior*, *34*(1), 35-40.
[53] Ainslie, G., & Haslam, N. (1992). Hyperbolic discounting.
[54] Nowatzki, N. R., & Williams, R. J. (2002). Casino self-exclusion programmes: A review of the issues. *International Gambling Studies*, *2*(1), 3-25.
[55] Howell, B. L., Deb, P., Ma, S., Reid, R. O., Levy, J., Riley, G. F., ... & Shrank, W. H. (2017). Encouraging Medicare advantage enrollees to switch to higher quality plans: assessing the effectiveness of a “nudge” letter. *MDM Policy & Practice*, *2*(1), 2381468317707206.
[56] Schmidt, U., & Zank, H. (2005). What is loss aversion?. *Journal of risk and uncertainty*, *30*(2), 157-167.
[57] Thaler, R. H., & Ganser, L. J. (2015). Misbehaving: The making of behavioral economics.
[58] Noar, S. M., Rohde, J. A., Barker, J. O., Hall, M. G., & Brewer, N. T. (2020). Pictorial cigarette pack warnings increase some risk appraisals but not risk beliefs: a meta-analysis. *Human Communication Research*, *46*(2-3), 250-272.
[59] Veldwijk J, Essers BAB, Lambooij MS, Dirksen CD, Smit HA, de Wit GA. Survival or Mortality: Does Risk Attribute Framing Influence Decision-Making Behavior in a Discrete Choice Experiment? *Value in Health*. 2016;19(2):202-209. doi:10.1016/j.jval.2015.11.004
[60] Progress on household drinking water, sanitation and hygiene, 2000-2020 - UNICEF DATA. UNICEF DATA. Published July 2021. Accessed March 30, 2022. https://data.unicef.org/resources/progress-on-household-drinking-water-sanitation-and-hygiene-2000-2020/
[61] Haston JC, Miller GF, Berendes D, et al. Characteristics Associated with Adults Remembering to Wash Hands in Multiple Situations Before and During the COVID-19 Pandemic — United States, October 2019 and June 2020. *MMWR Morbidity and Mortality Weekly Report*. 2020;69(40):1443-1449. doi:10.15585/mmwr.mm6940a/

[63] Czeisler MÉ, Garcia-Williams AG, Molinari NA, et al. Demographic Characteristics, Experiences, and Beliefs Associated with Hand Hygiene Among Adults During the COVID-19 Pandemic — United States, June 24–30, 2020. *MMWR Morbidity and Mortality Weekly Report*. 2020;69(41):1485-1491. doi:10.15585/mmwr.mm6941a3
[64] Hygiene Fast Facts. Published 2022. Accessed April 10, 2022. https://www.cdc.gov/healthywater/hygiene/fast_facts.html#:~:text=Hand%20Hygiene,disease%20by%20up%20to%2050%25.&text=Researchers%20estimate%20that%20if%20everyone,a%20year%20could%20be%20prevented.
[65] Hammond B, Ali Y, Fendler E, Dolan M, Donovan S. Effect of hand sanitizer use on elementary school absenteeism. *American Journal of Infection Control*. 2000;28(5):340-346. doi:10.1067/mic.2000.107276
[66] Hand Hygiene in Healthcare Settings. Published 2022. Accessed April 10, 2022. https://www.cdc.gov/handhygiene/index.html
[67] Isolation Precautions. Published 2022. Accessed April 10, 2022. https://www.cdc.gov/infectioncontrol/guidelines/isolation/index.html
[68] Frequent Questions About Hand Hygiene. Published 2022. Accessed April 10, 2022. https://www.cdc.gov/handwashing/faqs.html
[69] Ballard J. Many Americans don’t always wash their hands after going to the bathroom. Yougov.com. Published January 30, 2020. Accessed April 10, 2022. https://today.yougov.com/topics/lifestyle/articles-reports/2020/01/30/hand-washing-soap-poll-survey
[70] Ledderer L, Kjær M, Madsen EK, Busch J, Fage-Butler A. Nudging in Public Health Lifestyle Interventions: A Systematic Literature Review and Metasynthesis. *Health Education & Behavior*. 2020;47(5):749-764. doi:10.1177/1090198120931788
[71] Dai H, Saccardo S, Han MA, et al. Behavioural nudges increase COVID-19 vaccinations. *Nature*. 2021;597(7876):404-409. doi:10.1038/s41586-021-03843-2
[72] Penn Medicine Nudge Unit |. Upenn.edu. Published 2022. Accessed April 10, 2022. https://nudgeunit.upenn.edu/
[73] Arno A, Thomas S. The efficacy of nudge theory strategies in influencing adult dietary behaviour: a systematic review and meta-analysis. *BMC Public Health*. 2016;16(1). doi:10.1186/s12889-016-3272-x
[74] Zlatevska N, Dubelaar C, Holden SS. Sizing up the Effect of Portion Size on Consumption: A Meta-Analytic Review. *Journal of Marketing*. 2014;78(3):140-154. doi:10.1509/jm.12.0303
[75] Which Healthy Eating Nudges Work Best? A Meta-Analysis of Field Experiments | Marketing Science. Marketing Science. Published 2022. Accessed April 10, 2022. https://pubsonline.informs.org/doi/abs/10.1287/mksc.2018.1128?casa_token=es-sWXv9WykAAAAA%3A7f1IryXmwLEGRYkZRwSVjs8rmvUnl4W5nJOnUbAuu15lcKQ9SZVWPShTWLOSryq8fmWJS9Eep0Tj&journalCode=mksc
[76] Reñosa MDC, Landicho J, Wachinger J, et al. Nudging toward vaccination: a systematic review. *BMJ Global Health*. 2021;6(9):e006237. doi:10.1136/bmjgh-2021-006237
[77] A 680,000-person megastudy of nudges to encourage vaccination in pharmacies. PNAS. Published 2022. Accessed April 10, 2022. https://www.pnas.org/doi/10.1073/pnas.2115126119
[78] The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains. PNAS. Published 2022. Accessed April 10, 2022. https://www.pnas.org/doi/10.1073/pnas.2107346118
[79] Research Guides: Systematic Reviews & Other Review Types: What is a Systematic Review? Temple.edu. Published 2019. Accessed April 10, 2022. https://guides.temple.edu/c.php?g=78618&p=4178713

[80] Ganeshkumar P, Gopalakrishnan S. Systematic reviews and meta-analysis: Understanding the best evidence in primary healthcare. *Journal of Family Medicine and Primary Care*. 2013;2(1):9. doi:10.4103/2249-4863.109934
[81] The Campbell Collaboration. Campbellcollaboration.org. Published 2022. Accessed April 10, 2022. https://www.campbellcollaboration.org/#
[82] PRISMA. Prisma-statement.org. Published 2015. Accessed April 10, 2022. http://www.prisma-statement.org/
[83] Littell, J. H., Valentine, J. C., & Pigott, T. D. Unit 1: Introduction. In J. C. Valentine, J. H. Littell, & S. Young (Eds.), *Systematic reviews and meta-analysis: A Campbell Collaboration online course*. Open Learning Initiative, 2021. Available from https://oli.cmu.edu/courses/systematic-reviews-and-meta-analysis/
[84] Primary, Secondary, and Meta-Analysis of Research on JSTOR. Jstor.org. Published 2017. Accessed April 10, 2022. https://www.jstor.org/stable/1174772?seq=1
[85] Methley AM, Campbell S, Chew-Graham C, McNally R, Cheraghi-Sohi S. PICO, PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. *BMC Health Services Research*. 2014;14(1). doi:10.1186/s12913-014-0579-0
[86] Thiese MS. Observational and interventional study design types; an overview. *Biochemia Medica*. 2014;24(2):199-210. doi:10.11613/bm.2014.022
[87] Zotero | About. Zotero.org. Published 2022. Accessed April 10, 2022. https://www.zotero.org/about/
[88] Štefančič, V., & Jevšnik, M. (2020). Nudge tools for improving hygiene behavior among food handlers: Case study. *Journal of Food Safety*, *40*(5), e12836.
[89] Yoong SL, Hall A, Stacey F, et al. Nudge strategies to improve healthcare providers' implementation of evidence-based guidelines, policies and practices: a systematic review of trials included within Cochrane systematic reviews. *Implementation Science*. 2020;15(1). doi:10.1186/s13012-020-01011-0
[90] Bolton, L. (2021). WASH in schools for student return during the COVID-19 pandemic.
[91] Rosenstock, I. M. (1974). The health belief model and preventive health behavior. *Health education monographs*, *2*(4), 354-386.
[92] Witte, K. (1992). Putting the fear back into fear appeals: The extended parallel process model. *Communications Monographs*, *59*(4), 329-349.
[93] Iversen AM, Stangerup M, From-Hansen M, et al. Light-guided nudging and data-driven performance feedback improve hand hygiene compliance among nurses and doctors. *Am J Infect Control*. 2021;49(6):733-739. doi:10.1016/j.ajic.2020.11.007
[94] Iversen AM, Kavalaris CP, Hansen R, et al. Clinical experiences with a new system for automated hand hygiene monitoring: A prospective observational study. *American Journal of Infection Control*. 2020;48(5):527-533. doi:10.1016/j.ajic.2019.09.003
[95] Hansen MB, Wismath N, Fritz E, Heininger A. Assessing the clinical accuracy of a hand hygiene system: Learnings from a validation study. *American Journal of Infection Control*. 2021;49(7):963-965. doi:10.1016/j.ajic.2021.01.006
[96] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71
[97] Aarestrup, S., Moesgaard, F., & Schuldt-Jensen, J. (2016). Nudging hospital visitors' hand hygiene compliance.
[98] Deshmukh, A., Babu, S. K., Unnikrishnan, R., Ramesh, S., Anitha, P., & Bhavani, R. R. (2019, October). Influencing hand-washing behaviour with a social robot: Hri study with school children in rural india.

In *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)* (pp. 1-6). IEEE.

[99] Dreibelbis, R., Kroeger, A., Hossain, K., Venkatesh, M., & Ram, P. K. (2016). Behavior change without behavior change communication: nudging handwashing among primary school students in Bangladesh. *International journal of environmental research and public health*, *13*(1), 129.
[100] Grover, E., Hossain, M. K., Uddin, S., Venkatesh, M., Ram, P. K., & Dreibelbis, R. (2018). Comparing the behavioural impact of a nudge-based handwashing intervention to high-intensity hygiene education: a cluster-randomised trial in rural Bangladesh. *Tropical medicine & international health*, *23*(1), 10-25.
[101] Hansen, P. G., Larsen, E. G., Modin, A., Gundersen, C. D., & Schilling, M. (2021). Nudging hand hygiene compliance: a large-scale field experiment on hospital visitors. *Journal of Hospital Infection*, *118*, 63-69.
[102] King, D., Vlaev, I., Everett-Thomas, R., Fitzpatrick, M., Darzi, A., & Birnbach, D. J. (2016). "Priming" hand hygiene compliance in clinical environments. *Health Psychology*, *35*(1), 96.
[103] Mlakar, T., Mihelič Zajec, A., & Jevšnik, M. (2017). Use of a nudge tool for improving hand hygiene in a nursing team in home for elderly people-case study. *Sanitarno inženirstvo*, *11*(1), 33-46.
[104] Mobekk, H., & Stokke, L. (2020). Nudges emphasizing social norms increased hospital visitors' hand sanitizer use. *Behavioral Science & Policy*, *6*(2), 51-57.
[105] Naluonde, T., Wakefield, C., Markle, L., Martin, A., Tresphor, C., Abdullah, R., & Larsen, D. A. (2019). A disruptive cue improves handwashing in school children in Zambia. *Health promotion international*, *34*(6), e119-e128.
[106] Palinko, O., Fredskild, T. U., Andersen, E. T., Heidtmann, C., Sørensen, A. R., Junge, R. P., ... & Krüger, N. (2021, August). A Robotic Interface for Motivating and Educating Proper Hand Sanitization using Speech and Gaze Interaction. In *2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN)* (pp. 763-769). IEEE.
[107] Pfattheicher, S., Strauch, C., Diefenbacher, S., & Schnuerch, R. (2018). A field study on watching eyes and hand hygiene compliance in a public restroom. *Journal of Applied Social Psychology*, *48*(4), 188-194.
[108] Weijers, R. J., & de Koning, B. B. (2021). Nudging to increase hand hygiene during the COVID-19 pandemic: A field experiment. *Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement*, *53*(3), 353.
[109] Wichaidit, W., Naknual, S., Kleangkert, N., & Liabsuetrakul, T. (2020). Installation of pedal-operated alcohol gel dispensers with behavioral nudges and changes in hand hygiene behaviors during the COVID-19 pandemic: A hospital-based quasi-experimental study. *Journal of Public Health Research*, *9*(4).
[110] Wiik, H. (2019). *"Targeting Hand Hygiene to increase the Public Health Resilience in The Norwegian Army". A Quasi-experimental design* (Master's thesis, UiT Norges arktiske universitet).
[111] Bland JM. Statistics Notes: The odds ratio. *BMJ*. 2000;320(7247):1468-1468. doi:10.1136/bmj.320.7247.1468
[112] Wilson DB. Effect Size Calculator. Campbellcollaboration.org. Published 2022. Accessed April 10, 2022. https://www.campbellcollaboration.org/escalc/html/EffectSizeCalculator-Home.php
[113] Sutton, A. J., Abrams, K. R., Jones, D. R., Jones, D. R., Sheldon, T. A., & Song, F. (2000). *Methods for meta-analysis in medical research* (Vol. 348). Chichester: Wiley.
[114] Cooper, H., Hedges, L. V., & Valentine, J. C. (Eds.). (2019). *The handbook of research synthesis and meta-analysis*. Russell Sage Foundation.
[115] Kenward, M. G., & Roger, J. H. (1997). Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics*, 983-997.
[116] Hall, J. A., & Rosenthal, R. (1995). Interpreting and evaluating meta-analysis. *Evaluation & the Health Professions*, *18*(4), 393-407.

[117] Tian, Y., Schuemie, M. J., & Suchard, M. A. (2018). Evaluating large-scale propensity score performance through real-world and synthetic data experiments. *International journal of epidemiology*, *47*(6), 2005-2014.

[118] Hedges, Larry V., Elizabeth Tipton, and Matthew C. Johnson. "Robust Variance Estimation in Meta-Regression with Dependent Effect Size Estimates." *Research Synthesis Methods* 1, no. 1 (January 1, 2010): 39–65. https://doi.org/10.1002/jrsm.5.

[119] Rodgers, M. A., & Pustejovsky, J. E. (2021). Evaluating meta-analytic methods to detect selective reporting in the presence of dependent effect sizes. *Psychological methods*, *26*(2), 141.

[120] Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. Journal of Statistical Software, 36(3), 1-48. https://doi.org/10.18637/jss.v036.i03

[121] Fisher Z, Tipton E, Zhipeng H, Maintainer. *Package "Robumeta" Type Package Title Robust Variance Meta-Regression*.;2017.https://cran.rproject.org/web/packages/robumeta/robumeta.pdf

[122] R: What is R? R-project.org. Published 2022. Accessed April 10, 2022. https://www.r-project.org/about.html

[123] Caris, M. G., Labuschagne, H. A., Dekker, M., Kramer, M. H., van Agtmael, M. A., & Vandenbroucke-Grauls, C. M. (2018). Nudging to improve hand hygiene. *Journal of Hospital Infection*, *98*(4), 352-358.

[124] Stangerup, M., Kavalaris, C. P., From-Hansen, M., Hansen, M. B., Hansen, R., Hesselbo, B., ... & Knudsen, J. D. (2020). Significantly Improved Hand Hygiene Compliance Using Nudging and Performance Feedback Based on Data from an Automated Monitoring System. *American Journal of Infection Control*, *48*(8), S56-S57.

[125] Štefančič, V., & Jevšnik, M. (2020). Nudge tools for improving hygiene behavior among food handlers: Case study. *Journal of Food Safety*, *40*(5), e12836.

[126] Stirapongsasuti, S., Thonglek, K., Misaki, S., Nakamura, Y., & Yasumoto, K. (2021, September). INSHA: Intelligent Nudging System for Hand Hygiene Awareness. In *Proceedings of the 21st ACM International Conference on Intelligent Virtual Agents* (pp. 183-190).

[127] Watson, J., Dreibelbis, R., Aunger, R., Deola, C., King, K., Long, S., ... & Cumming, O. (2019). Child's play: Harnessing play and curiosity motives to improve child handwashing in a humanitarian setting. *International journal of hygiene and environmental health*, *222*(2), 177-182.