A meta-analytic cognitive framework of nudge and sludge

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Abstract

Public and private institutions worldwide have gained considerable traction in developing interventions to alter people's behaviors in predictable ways without limiting the freedom of choice or significantly changing the incentive structure (Thaler & Sunstein, 2008). A nudge is defined as an intervention to facilitate actions by minimizing friction and removing impediments, while a sludge is defined as an intervention that inhibits actions by increasing friction. While the terms nudge and sludge have garnered significant attention in behavioral economics, psychology, and public policy, the underlying cognitive mechanisms behind these interventions and their impact on behavior change remain largely unknown. We develop a novel cognitive framework by classifying these interventions along six cognitive processes: attention, perception, memory, effort, intrinsic motivation, and extrinsic motivation. In addition, we conduct a meta-analysis of field experiments (i.e., randomized controlled trials) (n=179 papers, k=222 observations, N=4,440,011 participants) from 2008 to 2020 to examine the effect size of these interventions targeting each cognitive process. Our findings demonstrate that effort-reducing interventions (e.g., convenience) are more effective than intrinsic motivation interventions (e.g., commitment-making) to change behaviors. Interventions that reduce or increase friction had similar effect sizes, although there were considerably fewer sludge studies (k=44) conducted to date than nudge ones (k=178). This new meta-analytic framework provides cognitive principles for organizing nudge and sludge with corresponding behavioral impacts. The insights gained from this framework help inform the design and development of future interventions based on cognitive insights.

Keywords: nudge, sludge, cognition, behavior change, randomized controlled trials

Introduction

Behavior change approaches have been extensively explored and tested in both public and private sectors that involve human choices. Traditionally, governments implement laws, regulations, taxes, or financial subsidies to promote or inhibit citizens' behaviors to achieve desirable outcomes. These interventions are considered as "hard" paternalism given that they aggressively restrict people's freedom to choose (Sunstein, 2014). Although these paternalistic interventions are useful, many theorists have criticized them for violating people's autonomy.

To address this concern, Sunstein and Thaler (2003) introduced the concept of libertarian or "soft" paternalism that allows planners to affect people's behaviors in a way that increases people's welfare while respecting their freedom of choice. Furthermore, they (2008) introduced the term 'nudge' which is a change in the choice architecture (i.e., the context in which choices are presented to people) that alters people's behaviors without limiting the freedom to choose or significantly changing the incentive structure. Since then, choice architects from public and private institutions have gained considerable traction in developing and testing nudge and sludge interventions that reduce or increase friction to complement traditional policy interventions. Many governments around the world, for example, have implemented graphic health warnings on cigarette packages to deter people from smoking, in addition to the conventional tobacco tax (Azagba & Sharaf, 2012).

More recently, several scholars introduced another term, sludge, to refer to situations where the context impedes behavior by creating frictions (see Soman et al. 2019, Sunstein 2019). In this paper, we use the term *nudge* to mean an intervention that facilitates actions by minimizing decision friction, while we use the term *sludge* to mean an intervention that deters actions by increasing decision friction (Thaler, 2018).

Since most practitioners are interested in solving real-world problems with limited resources, they tend to prioritize the process of identifying effective interventions over understanding why an intervention works or fails (Osman et al., 2020). Consequently, little research has explored the psychological mechanisms underlying these interventions. To address this gap, we first review existing frameworks that classify interventions that reduce decision friction and provide guidance on how to design and implement effective interventions. Next, we propose a new cognitive framework that addresses the limitations in the existing frameworks and categorizes interventions that reduce or increase decision friction based on six well-understood cognitive processes: attention, perception, memory, effort, intrinsic motivation, and extrinsic motivation. Finally, we conduct a meta-analysis of field experiments and objective behavioral outcome measures to examine the effect size of interventions targeting each of the six cognitive processes.

Existing frameworks of "nudge" interventions

Hansen and Jespersen (2013) have proposed a theoretical framework to explain the strength of nudge using a four-quadrant model with two dimensions: 1) type of thinking and 2) degree of transparency. The first dimension reflects System 1 and System 2 thinking processes (Kahneman, 2011; Stanovich & West, 2000), where System 1 allows people to make automatic, intuitive, and effortless decisions, and System 2 requires slow, deliberate, and effortful processing of information before making decisions. The second dimension is based on how much decision-makers know about the intention of the intervention. The purpose of a transparent nudge is straightforward and easily noticeable, but the intention of a non-transparent nudge is obscure and unnoticeable. This model therefore describes four types of nudge. A transparent System 1 nudge discloses its intention but influences behavior automatically (e.g., flashing lights

to draw attention to a sign). A transparent System 2 nudge reveals its purpose to decision-makers and prompts thinking before a decision (e.g., seat belt alarm). A non-transparent System 1 nudge automatically and subtly changes behavior (e.g., reducing the size of plates to reduce calorie intake). Lastly, a non-transparent System 2 nudge requires deliberate thinking but its intention is unnoticeable (e.g., framing the risks of surgery in terms of survival or mortality rates to alter risk perception). Of the four types, only non-transparent nudge truly manipulates choices and behaviors as the intention of these interventions is concealed. This framework therefore includes an ethical component of nudge evaluation.

Löfgren and Nordblom (2020) recently claimed that nudge can influence an inattentive choice, which relies on System 1, but not an attentive choice, which depends on System 2. If the decision-maker perceives a choice to be less important, they would make inattentive decisions that are easier to influence than attentive ones. The authors further argue that the effectiveness of nudge also depends on decision-makers' confidence in choosing the correct option inattentively. To illustrate, the authors categorized nudge as either "preference nudge" or "pure nudge." A preference nudge is one where a single option is clearly more desirable than the other. As an example, displaying a normative message stating that the majority of guests reuse their towels can increase the reuse rate (Goldstein et al., 2008). A preference nudge is more effective when a decision-maker has high confidence while making an inattentive choice. In the previous example, a hotel guest is unlikely to see the choice to reuse a towel as an important one, but would likely have high confidence that reusing the towel would be the better choice for the environment. A pure nudge, in contrast, does not direct a person's preference toward an option (e.g., default). The authors suggest that a pure nudge is more effective when the decision-maker is less confident in choosing the optimal option inattentively. For example, an opt-out system

was more effective in promoting contributions to carbon offset programs among naïve travelers (Araña & León, 2013), but its effect attenuated among environmental economists (Löfgren et al., 2012). Overall, this framework argues that nudge interventions are more effective in altering inattentive choices, and importantly, that choice architect must account for the confidence of decision-makers in choosing the optimal option.

Beyond the distinction of System 1 and System 2, other frameworks have primarily identified the most commonly used interventions to facilitate decisions. The MINDSPACE framework focused on nine specific interventions: messenger, incentives, norms, defaults, salience, priming, affect, commitment, and ego (Dolan et al., 2012). Messenger interventions use authority figures or ingroup members to deliver information to induce behavior change. For example, health educators were more persuasive than research assistants in promoting healthy behaviors (Webb & Sheeran, 2006). However, the robustness of this effect has been challenged in two recent studies that showed that receiving information from experts did not increase pro-environmental behavioral intentions (Hafner et al., 2019) or flu vaccination rates (Yokum et al., 2018). Incentives provide small financial rewards to encourage certain choices. For example, deposit contracts, which require people to change a certain behavior to earn back their initial deposit, were designed based on loss aversion, the tendency to avoid losses compared to equivalent gains (Kahneman & Tversky, 1979). Norm interventions are valuable given that people are substantially impacted by what others do (Cialdini et al., 1990). Defaults are considered by decision-makers as a recommended action, and switching to a non-default option is seen as losing the default option, which is undesirable (Johnson & Goldstein, 2003). Salience interventions, such as novelty, draw people’s attention to one option over others (Kahneman & Thaler, 2006). Priming interventions make relevant information of the desired behavior more

accessible to increase the likelihood of action (Richardson-Klavehn & Bjork, 1988). Affect interventions trigger strong emotional responses to promote behavior change. For example, seeing images of animals suffering increased behavioral intentions to protect animal welfare (Thomas-Walters et al., 2020). Commitment interventions target the fact that people abhor the social costs of failure. Moreover, making a commitment public is especially impactful given that people are afraid of reputational damage. Lastly, ego interventions intensify people's willingness to maintain a positive self-image. For instance, heterosexual male participants donated more when they were approached by an attractive female solicitor to maintain a positive self-image in the eyes of the opposite sex (Landry et al., 2006).

Building on the MINDSPACE framework, the Behavioural Insights Team aggregated the nine interventions into four recommendations of easy, attractive, social, and timely for choice architects, abbreviated as EAST. First, making a choice easy means that interventions should reduce barriers to action, for example by using default or simplification. Second, making it attractive means drawing people's attention toward the desired choice and complement it with rewards. Third, making it social means connecting people's behavior to others in the community, such as by showing what most people are doing or encouraging people to commit to an action publicly. Lastly, making it timely means nudging at an appropriate time and provide timely information, for example, by reminding people to pay a fine a few days before the due date (Service et al., 2014).

Since MINDSPACE and EAST provide guidelines for general behavior change, a recent framework, SHIFT, narrowed the scope to focus on the promotion of sustainable behaviors, by categorizing interventions that reduce friction into five psychological factors (White et al., 2019). Social influence aims to change behaviors by communicating how other people behave. Habit

interventions aim to make sustainable behaviors easier for consumers, for example, by making vegetarian meals the default. Individual self interventions target people's desire to maintain positive self-views, for instance, by emphasizing the ethical attributes of a climate-friendly product. Feelings and cognition interventions focus on eliciting positive or negative emotions and correcting misperceptions of a sustainable product. Finally, tangibility interventions encourage choice architects to make sustainable actions concrete and psychologically closer to people rather than presenting them in vague terms.

Existing frameworks of sludge interventions

Interventions that decrease or increase friction can both be beneficial or harmful for decision-makers (Sunstein, 2019; Thaler, 2018). Beneficial nudge interventions move people toward behaviors that increase their welfare by reducing decision friction (e.g., automatic enrollment in an employee pension plan). Beneficial sludge moves people away from harmful behaviors that reduce their welfare by increasing decision friction (e.g., an "Are you sure?" warning message designed to prevent impulsive decisions). Harmful nudge moves consumers toward options that are not in their best interest by reducing decision friction (e.g., automatic purchase of a subscription to a magazine against the consumer's intention). Harmful sludge moves consumers away from the beneficial choice they would otherwise make by increasing friction (e.g., filling out complex forms to get a rebate). Beneficial nudge and sludge are frequently employed by the public sector targeting the general public to collectively improve societal outcomes, while harmful nudge and sludge are more frequently observed in the private sector targeting consumers to increase revenues.

Soman et al. (2019) reformulated sludge as creating decision points for consumers to pause and think before continuing. Specifically, three methods were proposed to create decision

points. First, creating a transaction cost can interrupt impulsive consumption. For instance, giving the same amount of popcorn in six bags of equal quantities to consumers rather than in a large bucket could reduce over-consumption, since opening a new bag requires extra actions (Cheema & Soman, 2008). Second, providing reminders can redirect focus to a forgotten activity which may lead to the completion of the task. Third, introducing interruptions can deter a person from making an impulsive decision, for example by allowing a cooling-off period after signing a contract. Moreover, Soman et al. (2019) proposed three main sources of friction that could harm consumers: 1) increasing the complexity of the actual process to accomplish a task (e.g., requiring repetitive actions from consumers), 2) using a complicated communication style (e.g., concealing important information), and 3) creating a process that marginalizes specific groups (e.g., asking for a deposit may exclude people with financial constraints).

Recently, Mills (2020) proposed the concept of nudge and sludge symmetry. Specifically, when an intervention decreases decision friction associated with a specific option, it increases friction on all other options. For instance, automatically enrolling employees into a pension plan reduces friction, but it creates cognitive burdens for those who want to opt out of the plan. When an intervention increases decision fiction associated with a specific option, it decreases friction on all other options. There are three specific types of friction that can encourage or discourage decision making: 1) hedonic costs that change the comfort level of an option (e.g., displaying graphic health warnings), 2) social costs that target people's compliance to social norms (e.g., providing neighbors' energy consumption), and 3) obscurant costs that adjust the complexity to reach an option (e.g., including jargons in a document). Moreover, Mills (2020) redefined beneficial and harmful interventions with Pareto and rent-seeking interventions to minimize the

degree of subjectivity. A Pareto intervention benefits both the choice architect and decision-makers, but a rent-seeking intervention only benefits the choice architect.

In addition to the costs discussed above, Shahab and Lades (2021) enriched the type of costs based on the transaction-cost literature: 1) making the relevant information of different options harder to find (e.g., showing additional shipping costs at the end of the purchasing process), 2) increasing the difficulty to evaluate the advantages and disadvantages of different options (e.g., enhancing the benefits of a product but hiding its add-on costs), 3) making a desired option harder to reach (e.g., filling complex paperwork), and 4) creating negative experiences in decision-makers (e.g., using pressure selling). The authors also discussed three factors that can influence the degree of costs associated with a choice architecture. For example, a choice architecture that is highly specific, contains uncertainty, or is encountered infrequently (e.g., filling tax once a year) can create additional costs for the decision-makers.

The existing theoretical frameworks have discussed a number of effective interventions widely studied in the past literature. However, these frameworks did not explain the psychological mechanisms behind the interventions. Moreover, there are no systematic comparisons of the effectiveness of interventions that reduce or increase friction under a common framework.

A new cognitive framework

Our cognitive framework is organized along three dimensions. The first two dimensions are based on(Sunstein, 2019), where the first dimension is the type of intervention (reducing vs. increasing decision friction), and the second dimension is whether the intervention is beneficial or harmful. The third dimension is the type of cognitive processes involved in eliciting the desired behavior change intended by the intervention (see Table 1).

Table 1: Definitions of the six cognitive processes

Cognitive process	How each process is used in interventions that reduce or increase decision friction
Attention	Using bottom-up features (e.g., color) to increase or decrease the salience of an option
Perception	Framing the content of information to influence the conscious interpretation of the information
Memory	Using encoding cues or retrieval cues to alter subsequent decisions
Effort	Changing cognitive or physical ease associated with an option
Intrinsic motivation	Influencing inherent interests toward an option in the absence of external factors
Extrinsic motivation	Imposing external rewards or punishments to alter decisions

The six cognitive processes are motivated by the pioneering work of Maule (1985) who proposed that cognitive psychology can serve as a foundation for decision making research. In particular, decision making is determined by different stages of information processing: the first stage records sensory inputs which are heavily influenced by attention; the subsequent pattern recognition stage compares the incoming information to the previously stored information to recognize the sensory inputs; and the last memory stage retains the inputs permanently. The integration of these stages determines the final decision, but an important constraint in the integration is that these information processing stages have a limited capacity which may lead people to use simpler decision strategies (e.g., heuristics) to reduce the processing load. Thus, the amount of effort associated with an option can bias the decision making process. Moreover, Maule (1985) argued that motivation is an important factor in decision making, but cognitive psychology tends to neglect motivation. Given the connections between cognitive processes and decision making, the current framework classifies interventions under six cognitive processes: attention (e.g., highlighting), perception (e.g., framing), memory (e.g., reminders), effort (e.g., default), intrinsic motivation (e.g., social norm messaging), and extrinsic motivation (e.g., small

financial incentives). Table 2 outlines the entire cognitive framework with example interventions. In each of the following sections, we will discuss how each cognitive process is targeted in the interventions.

Table 2: A cognitive framework of common nudge and sludge

	Beneficial for people		**Harmful for people**	
Cognitive processes	**Nudge** (decrease friction to facilitate actions)	**Sludge** (increase friction to deter actions)	**Nudge** (decrease friction to facilitate actions)	**Sludge** (increase friction to deter actions)
Attention	• Abrupt onset • Cueing • Highlighting • Visibility	• "Are you sure" alert • Color warning • Increased font size of calories label	• Color (e.g., brand logo) • Sensory cues in casinos	• Concealment • Distracting notification • Reduced font size
Perception	• Appearance • Assortment size • Availability • Feedback • Gain framing • Graphics • Information	• Loss framing • Smaller portions	• Bundle pricing	• Decoy option • Price partitioning (e.g., taxes, shipping fees)
Memory	• Anchoring (e.g., suggested donation amount) • Reminder (e.g., promoting college enrollment) • Priming • Visual prompt	• Reminder (e.g., reducing water consumption)	• Anchoring (e.g., maximum deposit amount) • Repetitive advertising Subliminal advertising	• Absence of reminder at the end of trial periods
Effort	• Accessibility • Convenience • Default • Simplification	• Active choice • Inconvenience	• Accessibility to unhealthy food • Convenience (e.g., tabletop ATMs in casinos) • Default (e.g., overdraft protection)	• Complex cancellation procedures • Mail-in rebates • Non-transparent privacy settings
Intrinsic motivation	• Commitment making • Goal setting • Implementation intention • Motivational intervention • Social norm (e.g., promoting donation)	• Self-control tools • Social norm (e.g., reducing electricity consumption)	• Junk food advertising • Vaping norms for non-smokers	• Vaping norms for smokers who want to quit

Extrinsic motivation	• Financial incentives • Non-financial incentives (e.g., smiley stamps)	• Conditional incentives • Small fees for no-shows	• Micro-incentives to gamble	• Membership fees

Attention

Although attention has been defined in a variety of ways in cognitive psychology, one consensus is that people, given their limited cognitive capacity, are highly selective in attending to information in the environment (e.g., Broadbent, 1958; Driver, 2001; Knudsen, 2007; Treisman & Gelade, 1980; Wolfe, 1994). In other words, not all incoming information will be processed at the later stages. Given the limitation of the attentional capacity, attention is said to be controlled by both top-down and bottom-up factors (Corbetta & Shulman, 2002; Pashler et al., 2001; Posner, 1980). Top-down factors refer to prior expectations, knowledge, and internal goals that endogenously guide attention. Interventions that target top-down attention often involve other cognitive processes, such as working memory (Unsworth et al., 2020) or intrinsic motivation (Luo & Zhao, 2019). For example, internal goals can guide attention, but the procedure of creating internal goals often engages intrinsic motivation (e.g., goal-setting) rather than a pure attention intervention (Latham & Locke, 1979). For this reason, it is difficult to tease out top-down attentional interventions from interventions targeting other cognitive processes. On the other hand, bottom-up attention is relatively easier to target in interventions that use salient external stimuli that exogenously draw attention, such as color (Nagy & Sanchez, 1990), motion (M. Dick et al., 1987), size (Treisman & Gormican, 1988), and abrupt onset (Yantis & Jonides, 1984). Thus, an attention intervention in the current framework is defined as *an intervention that uses bottom-up features to increase or decrease the salience of an option*. The MINDSPACE framework used a similar but less precise definition of attention that stated that our attention can

be drawn by novel or relevant information (Dolan et al., 2012), but did not explain how interventions manipulated attention to change behaviors.

Although numerous bottom-up features can guide attention, the strength of each feature in guiding attention is unequal. Wolfe and Horowitz (2004, 2017) categorized these features on a scale from undoubted guiding attributes (e.g., color) to probably not guiding attributes (e.g., blur; Enns & MacDonald, 2013). To determine the most effective interventions, examples of behavioral interventions that manipulate undoubted guiding features, such as color, motion, and size, are discussed below. In addition to visual stimuli, bottom-up auditory cues have been shown to draw attention (Cherry, 1953; Dunifon et al., 2016; Mondor & Zatorre, 1995; Spence & Driver, 1994). In what follows, we discuss different interventions that draw bottom-up attention.

Color has been used extensively in past studies to increase the salience of a message. For example, highlighting the message of renewing license plate stickers in blue significantly increased the likelihood of license renewal among drivers (Castelo et al., 2015). This is a beneficial attention intervention that reduces friction because it draws people's attention to the desirable option that facilitates the renewal process. A beneficial intervention that increases friction is the use of color, especially red, to alert and hold people back from potential risks, such as a red warning before opening a phishing website (Egelman & Schechter, 2013), red warnings on alcohol bottles (Laughery et al., 1993; Pham et al., 2018) or web-based games (Gnambs et al., 2015). Moreover, labeling unhealthy food and drinks in red ink and healthy ones in green ink reduced the sales of unhealthy items (Thorndike et al., 2014). A potential harmful intervention that reduces friction from marketing research suggests that red and yellow colors have been frequently used as part of fast-food brand logos to gain attention, which may increase consumers' temptation for junk food (Singh, 2006).

In addition to color, abrupt onset can also draw bottom-up attention (Jonides & Yantis, 1988). Pop-out messages create an abrupt onset that draws people's attention to novel information or advice concerning an immediate behavior. For example, push notifications from mobile phone applications can increase news exposure among phone users, and those who enabled the notifications benefited by gaining knowledge on political issues, general civic facts, and current events (Stroud et al., 2020). Other studies have used this intervention for controlling body weight by sharing health tips (Hernández-Reyes et al., 2020), promoting engagement with mobile health applications (Bidargaddi et al., 2018), and reducing pregnancy anxiety (Jareethum et al., 2008). Apart from facilitating actions, pop-out messages such as a confirmation dialogue box can create a decision point to deter actions (Yifrah, 2019). Moreover, an online gambling operator helped gamblers to cease their playing session by adding a pop-up message after 1000 consecutive gambles (Auer et al., 2014), as a beneficial intervention that increases friction by making the continuation of playing more effortful. Despite the advantages of using push notification, research has shown that this intervention can induce task-irrelevant thoughts and undermine performance on attention-demanding tasks (Stothart et al., 2015). Thus, a pop-out notification could become a harmful intervention that increases friction, when it distracts people's attention from important tasks. For example, social networking applications frequently distract people's attention by sending updates via push notifications throughout the day (Deloitte, 2016; Pielot et al., 2014).

Another bottom-up cue is text font size, which has been used to intentionally conceal critical information from consumers' focus. An example of this type of harmful sludge is resort fee disclosures which are commonly printed in small font sizes to make it hard for consumers to notice (Kim, 2006; Sullivan, 2017).

Lastly, sounds can be used as a bottom-up cue to influence attention. Casinos have employed auditory cues to create an immersive environment that facilitates gamblers' decision to continue playing. These cues were shown to induce an urge to play and trigger risky decision making, especially when they are combined with occasional wins (Cherkasova et al., 2018; Dixon et al., 2014; Park et al., 2020). Moreover, modern gambling machines employ auditory and visual features not only to accompany a win but also to create a sense of a partial win after a loss to motivate further gambling, a technique known as "losses-disguised-as-wins" (Dixon et al. 2010; Newall, 2019).

Perception

A pioneering theory proposed that perception is a hypothesis testing process of the sensory inputs, based on prior experience or knowledge (Gregory, 1980). According to this theory, people continuously construct their understanding of the external world by integrating stored information from memory with incoming sensory information. The process was further separated into conscious and unconscious perceptual processes, the former requiring actively matching a hypothesis against sensory inputs, and the latter automatically transforming sensory information into mental representations (Marcel, 1983). Put simply, a person can perceive sensory information with or without awareness. From a cognitive perspective, perception is commonly known as the organization, identification, and interpretation of sensory inputs to create a mental representation of the external information (Schacter et al., 2011). In the nudge literature, to change perception, the interventions often present messages by reconstructing prior information under a new frame, which may influence subsequent behaviors. Thus, a perception intervention in the current framework is defined as *an intervention that frames the content of information to influence the conscious interpretation of the information*. Perception interventions

are distinct from attention interventions because they intend to change the semantic meaning of an option, rather than adjusting the physical features of the option (e.g., color). Previous interventions that reduce friction have primarily used framing techniques, presentation formats, and informational feedback to influence decision-makers' choices. Below we discuss existing interventions that target perception.

A popular perception intervention is to frame an option in terms of its associated benefits or costs to influence people's perception of the option, such as framing surgery risks as either a 90% survival rate or a 10% mortality rate (McNeil et al., 1982; Rothman & Salovey, 1997; Tversky & Kahneman, 1981). Highlighting the benefits is an intervention that reduces friction and highlighting the costs is an intervention that increases friction. Several meta-analyses have shown that benefit-framed messages (e.g., that exercising more lowers the risk of heart disease) are more effective than costs-framed messages (e.g., that by not exercising, the risk of heart disease increases) in changing health behaviors, such as smoking cessation and physical activity (Gallagher & Updegraff, 2012; Latimer et al., 2010; Toll et al., 2007; Williams et al., 2019). However, cost-framed messages are more effective in increasing physical checkups, such as testing for cholesterol levels (Bosone & Martinez, 2017; Keyworth et al., 2018; O'Keefe & Jensen, 2009). In addition to health, framing the beneficial outcomes of climate change mitigation (e.g., the amount of carbon emission can be reduced) increased pro-environmental attitudes (Spence & Pidgeon, 2010) and positive attitudes towards energy saving among environmentally concerned participants (Xu et al., 2015). In behavioral economics, framing a retirement investment plan as a monetary benefit rather than a cost significantly increased people's tendency to save earlier (Kim & McKinnon, 2020).

Another beneficial intervention that reduces friction is providing informational feedback to promote desirable behaviors. Informational feedback is considered a perception intervention because it informs people on the gap between the actual behavior and the desired behavior. In the environmental domain, consumers who perceived their real-time energy consumption and costs from an in-home energy display reduced electricity consumption by 7% (Faruqui et al., 2010). Providing immediate feedback on sorting accuracy in a recycling game promotes accurate recycling behaviors in multi-family residences for up to three weeks (Luo et al., 2019). In a medical context, displaying a graph of daily caloric intake helped patients with major burn injuries to achieve the prescribed calorie intake level (Mahon et al., 1984). Also, a monitoring system providing real-time glucose levels promoted better glycemic control among patients with type 2 diabetes (Yoo et al., 2020). Like framing interventions, real-time informational feedback can serve as a beneficial intervention that increases friction to deter people from undesirable behaviors, for example, immediate feedback on air quality reduced indoor smoking behaviors (Hovell et al., 2020).

Another beneficial intervention that increases friction commonly used to deter people from undesirable behaviors is visualizing cost-framed messages in terms of graphic warnings. Past studies showed that displaying adverse consequences of smoking on cigarette packages significantly reduced cigarette sales and decreased the prevalence of smoking (Bonfrer et al., 2020; Stead et al., 2013). Moreover, displaying the adverse health consequences of unhealthy foods effectively reduced the intention to choose unhealthy foods (Bollard et al., 2016; Hollands et al., 2011; Rosenblatt et al., 2019) and increased the purchase of healthy foods (Donnelly et al., 2018). Graphic warning labels also reduced preferences of alcoholic products (Al-Hamdani & Smith, 2015) and increased the intention to consume less alcohol (Wigg & Stafford, 2016).

Furthermore, images showing the adverse impacts of climate change have been extensively used in the media to convey the message of climate change to the public (Boomsma et al., 2016; Feldman & Hart, 2016; Nicholson-Cole, 2005). Images of suffering animals were effective in increasing intentions to protect animal welfare and donate more (Thomas-Walters et al., 2020). Seeing an animal trapped in plastic debris increased people's intention to reduce plastics (Septianto & Lee, 2020) and reduced their actual plastic waste (Luo et al., under review). A negatively valenced image illustrating child poverty also increased the intention to donate to charity (Chang & Lee, 2009).

In contrast to beneficial interventions, framing can be used for harm. In a field experiment, Ganzach & Karsahi (1995) found that conveying the losses of not using a credit card to cardholders doubled the percentage of cardholders starting to use their credit, and more than doubled the expenditures of these cardholders. This framing intervention is a harmful intervention that reduces friction because it increases the temptation to overspend. In marketing, retailers often adjust the presentation of prices to influence the perceived value of a product and increase purchase intentions. Price bundling has been a common and effective perceptual intervention used by retailers to increase revenues, but it may harm consumers' interests by increasing purchases of products that would otherwise be unwanted. For example, consumers are less sensitive to a single bundle price since they are more averse to multiple losses than a single loss with the same amount (Stremersch & Tellis, 2002). In other words, consumers perceive the sum of individual prices, such as a $5 burger, $3 fries, and a $2 soda, to cost more than a $10 combo. Thus, retailers use this pricing strategy to increase the purchase intention of complementary products (Harlam et al., 1995), for example, Amazon has used a bundled pricing

model to recommend complementary products to consumers to boost online sales (Informed.co, 2018).

Aside from price bundling strategies, partitioning a product's price into multiple components (e.g., taxes, fees, surcharges) is another harmful intervention that can impair the accurate perception of the total cost by increasing complexity (Greenleaf et al., 2016). Hossain and Morgan (2006) found that consumers tend to ignore shipping costs in eBay auctions, which may explain why retailers prefer tax-exclusive price tags. In addition, there is a trend where retailers subtly reduce the portion of food products to maintain a low price (Gayle, 2016). Although this practice is clearly counter to the interests of consumers when used to increase profits while providing less product, decreasing portion size can be a beneficial intervention that increases friction to deter people from eating unhealthy foods and producing food waste (Freedman & Brochado, 2010; Wansink et al., 2014). Another instance of a harmful intervention that increases friction is to add a decoy option (usually more profitable) that is similar but inferior to a target option, which prevents consumers from choosing the option best suited to their needs (Huber et al., 1982). For example, among the three storage configurations of the iPhone 12 (i.e., $1129 for 64GB, $1199 for 128GB, and $1339 for 256GB), the 64GB model seems to be a decoy option that moves consumers toward the 128GB model, because consumers perceive that a small extra charge allows them to buy a phone with a substantially larger storage capacity. A recent case study has confirmed that the decoy effect can significantly increase profits for retailers (Wu & Cosguner, 2020).

Memory

In the current framework, a memory intervention is defined as *an intervention that uses encoding cues or retrieval cues to alter behaviors*. This definition is supported by the multi-store

model of memory which explains how external information is transferred and stored into long-term memory in three stages (Atkinson & Shiffrin, 1968). The initial sensory encoding stage creates an immediate registration of the stimulus, but most registered information decays instantaneously. An accurate representation of a visual image, for example, fades out within several hundred milliseconds. The initial encoding stage was divided into automatic and effortful processes (Hasher & Zacks, 1979). The automatic encoding of spatial location, time, or the number of occurrences involves minimal attentional resources, while the effortful encoding process which is engaged during rehearsal requires deliberate attention. Priming and anchoring interventions can incidentally influence the encoding process to enhance the registration of new information. In the second short-term stage, registered information is stored for a longer time than the encoding stage. In the last long-term stage, information is stored almost permanently while the remaining information in the first two stages fades completely. The persistence of memory depends on the strength of the perceptual analysis of the sensory information, where deeply analyzed information forms longer-lasting memory traces (Craik & Lockhart, 1972).

Despite the deliberate encoding process or deep perceptual analysis, forgetting is unavoidable over time. Cue-dependent forgetting theory suggests that memory decay occurs due to the absence of relevant retrieval cues to access the stored information (Tulving, 1974). Choice architects frequently use retrieval cues, such as reminders and visual prompts, to encourage or discourage subsequent actions. Below we discuss existing interventions that target memory.

Presenting a numerical anchor at the encoding stage is another harmful intervention that can bias consumers' purchasing decisions against their own interests by reducing friction. A lab study showed that participants were willing to spend more money in a restaurant that had a name associated with a higher number (e.g., Studio 97) than a smaller number (e.g., Studio 17;

Critcher & Gilovich, 2008). A field experiment demonstrated that limiting the purchase of discounted items with a higher number (e.g., 12 per person vs. 4 per person) increased the sales of discounted items, suggesting that consumers' purchasing decisions relied on an irrelevant anchor (Wansink et al., 1998). Furthermore, gambling websites explicitly provide a maximum deposit amount that is extremely high to serve as an anchor to increase the average deposit (The Behavioual Insights Team, 2018). A modeling study showed that in real estate, higher listing prices are associated with higher selling prices, even after controlling for sellers' motivations and the quality of the property (Bucchianeri & Minson, 2013).

Since rehearsal can enhance the encoding of new information in memory, one intervention is to repetitively expose people to a stimulus, which can subsequently bias their choice. As a beneficial intervention that reduces friction, exposing participants to a recycling advertisement multiple times increased their intention to recycle (Ma et al., 2014). A harmful intervention that reduces friction is repetitive advertising to increase consumers' positive attitudes toward an unfamiliar brand (Calder & Sternthal, 1980; Campbell & Keller, 2003) and to boost recollection of the brand name (Burke & Srull, 1988). Repetitive banner advertisements on websites can enhance consumers' recall of the advertisement and their intention to click (Yaveroglu & Donthu, 2008).

To address forgetting, a well-studied beneficial intervention that reduces friction is reminders that help people retrieve a planned behavior, such as sending a text message to remind patients to take medication regularly. The text message is a retrieval cue that aids patients towards the actions they already intended to do. In the current framework, reminders are not considered as attention interventions, because the function of reminders is to help people retrieve stored information rather than draw their attention to new information. Several fields have used

reminders in the form of text messages, phone calls, or emails to increase people's adherence to their planned behaviors.

In healthcare, a major challenge in treating chronic diseases is poor adherence to the recommended treatment program. Around half of patients do not adhere to their treatment plans, and this rate is even higher when the complexity of the treatment increases (Martin et al., 2005; World Health Organization, 2003). To address the adherence challenge, healthcare providers have developed a reminder system to improve patient adherence. A meta-analysis showed that the number of doses taken by patients in the group that received reminders was higher than patients in the control group (Fenerty et al., 2012). Moreover, short message service reminders increased the attendance rate of medical appointments in patients (Gurol-Urganci et al., 2013; Guy et al., 2012; Robotham et al., 2016). To promote healthy behaviors, weekly reminders helped to maintain healthy step counts among university employees throughout the winter break (Gell & Wadsworth, 2015). Reminders can also be used as beneficial interventions that create a cognitive barrier to deter people from unhealthy behaviors, such as reminders of the health risks of alcohol consumption before drinking (van Leeuwen et al., 2019; van Lettow et al., 2015). In economics, monthly reminders from banks increased clients' adherence to a saving commitment plan compared to clients who did not receive reminders (Karlan et al., 2016). Similarly, sending text message reminders before a trial effectively reduced the rate of failure to appear in court by 21%, regardless of the message content (Fishbane et al., 2020).

Another type of retrieval cue is a static visual prompt to remind people of a beneficial behavior. Visual prompts have been frequently used as a beneficial intervention to promote pro-environmental behaviors by reducing friction. One study showed that posting recycling prompts on the bins increased recycling behavior (Austin et al., 1993). Visual prompts have also

effectively encouraged people to turn off lights in unoccupied washrooms (Feng & Zhang, 2019; Sussman & Gifford, 2012). Visual prompts can also serve as a beneficial intervention that creates friction to deter people from making undesirable decisions. For example, posting signs that ask people to rethink their reason to smoke reduced the number of cigarette butts (and therefore, presumably, cigarettes smoked) at the smoking areas of a college campus by 35% (Hodges et al., (1999). Voice prompts, such as verbally asking customers whether they need a plastic bag, effectively deterred people from automatically grabbing a plastic bag at the checkout of grocery stores, resulting in a reduction of plastic bag consumption (Ohtomo & Ohnuma, 2014). Finally, a potentially harmful intervention that increases friction by preventing consumers from remembering to perform an important action is the absence of reminders before the end of a free trial or subscription period. To retain customers and increase profits, service providers may elect not to send a reminder to notify their consumers about the upcoming expiration of the free trial period. To overcome this memory failure, consumers are forced to turn to third-party applications to remind them of the cancellation date (Michaels, 2019). Unsurprisingly, many third-party applications also tend to employ free trial periods and do not remind consumers to cancel. As a cautionary note, priming techniques may facilitate decisions using encoding cues (e.g., King et al., 2016; North et al., 1997; Wryobeck & Chen, 2003), but many priming studies have not been well replicated.

Effort

Effort interventions are defined as those that *modify the cognitive or physical ease associated with an option* in the current framework. Nudge minimizes the cognitive or physical effort in executing an action, and sludge maximizes the cognitive or physical effort. The definition of effort interventions is derived from research on effort in decision making. One

model suggests that effortful decisions are cognitively demanding and time-consuming (Bettman et al., 1990). In addition to cognitive effort, physical effort is any physical demand to complete a task, such as the walking distance to the recycling bin.

It is widely accepted that people tend to choose an option that requires minimum cognitive or physical effort, which is known as "the law of less work" (Kahneman, 2011; Kool et al., 2010). For example, people prefer to maintain the status quo instead of switching to an alternative choice (i.e., status quo bias). In one study, participants who were told that they inherited a portfolio already invested in a moderate-risk company's stock chose to retain this portfolio rather than switching to an alternative investment portfolio (Samuelson & Zeckhauser, 1988). Also, the larger the effort previously invested in the status quo option, the more likely people are to retain it. Kahneman et al. (1991) propose that people tend to retain the status quo because they are loss averse. That is, giving up the status quo is considered a loss, and significantly higher gains are required to motivate switching to an alternative option. This explanation can be reframed in terms of cognitive effort: choosing a new option is more cognitively demanding than keeping the current option. Shugan (1980) suggests that more effort is required to abandon the status quo when more alternative options are available compared to a single alternative option. Thus, examining fewer alternatives can significantly reduce cognitive demands (Shah & Oppenheimer, 2008). Another explanation for the status quo bias is that counterfactual thoughts induced by switching to an alternative option produce greater regret than keeping the status quo, and therefore decision-makers prefer inaction to action (Kahneman & Miller, 1986). Choice architects have designed interventions that change the degree of complexity, accessibility, or convenience associated with an option. Below we discuss existing interventions that target effort.

One beneficial intervention that minimizes cognitive effort is to simplify complex messages or procedures. National field experiments showed that simplifying lengthy and verbose letters sent by the tax authority increased tax filing and tax payment (Neve et al., 2019) and led to higher take-up of social benefits (Bhargava & Manoli, 2015). Simplifying the completion process of student financial aid applications with the help of tax professionals substantially increased college enrollment and the received amount of financial aid (Bettinger et al., 2009). A different type of simplification that minimizes cognitive burdens is to visualize complex information. For example, showing the impacts of an earthquake in a vivid image effectively motivated people to support earthquake risk mitigation initiatives, compared to cold statistics of earthquakes (Lok et al., 2019). Other beneficial interventions aim to introduce the most convenient option that minimizes physical effort. A field study showed that placing compost and recycling bins on each floor instead of in the basement significantly increased waste diversion (DiGiacomo et al., 2018). Putting healthy foods at the cash register desk increased sales of healthy products (Kroese et al., 2016). An alternative beneficial intervention is inducing friction while accessing unhealthy food or making environmental-unfriendly choices. The City of Vancouver (2020) requires all food vendors to provide straws on request only, which reduced the accessibility of straws.

Convenience can also be used against consumers' interests as a harmful intervention that reduces friction. For instance, modern gambling machines with touchscreen buttons require less physical effort during long gambling sessions, compared to traditional machines with a lever. Likewise, online gambling platforms have made gambling activities more accessible (Newall, 2019). Recently, Palm Casino Resort located in Las Vegas planned to install automated cash systems at gambling tables to eliminate trips to the ATMs for gamblers (Carter, 2019). Harmful

sludge maximize cognitive or physical effort to restrict consumers' choices. A typical example is to make the cancellation process as complex as possible to retain customers. Purchasing a cable TV subscription can be easily done online, but canceling the subscription requires a tedious phone call with customer service (Lunn, 2019). Another example is mail-in rebates which require considerable effort because of the complex redemption rules and long wait times for the rebates. One study estimated that 40% of mail-in rebates were unclaimed and an additional 20% of mail-in rebates were disqualified every year (Ong, 2008). Another harmful intervention is to make privacy settings harder to change. Facebook used to have complex privacy settings which prevented users from protecting their personal information, but after the Cambridge Analytica scandal, Facebook changed its privacy setting page to make it more transparent (Lomas, 2018). Finally, the long wait time can be harmful, for example, long wait times for healthcare services can lead to adverse consequences for patients (Reichert & Jacobs, 2018). However, long wait times as a cooling-off period create a decision point that allows people to pause and reassess their decisions, which can be beneficial. One study showed that enforcing a waiting period between the purchase day of firearms and the receiving day reduced gun homicides by approximately 17% (Luca et al., 2017).

Motivated by the status quo bias, choice architects have used default to minimize the effort by making the desirable option as the status quo. Making organ donation as the default choice increased the rate of donation in several European countries (Johnson & Goldstein, 2003). Although setting organ donation as the default is a controversial policy, making it the default option can benefit people who are willing to donate by reducing physical effort such as filling out complex forms. Other studies have shown that making green energy as the default purchase option increased green energy purchases in German households than making it as an opt-in

option (Ebeling & Lotz, 2015); and automatically enrolling employees in a retirement saving plan significantly increased participation rate (Choi et al., 2004).

This said, default can also be a harmful intervention that reduces friction. For example, automatically enrolling consumers in overdraft protection programs can cause people to pay higher interest rates (Sunstein, 2017). Another example is to automatically renew a membership or subscription for consumers who do not intend to renew, which can increase revenues. Although the data on revenue increase due to the auto-renewal process is not publicly available, a marketing survey showed that automatic renewal is the most common approach among membership organizations to retain their members (Rossell et al., 2020). An empirical study showed that the default add-on led to larger travel package purchases and generated more revenues (Steffen et al., 2019).

In contrast to default, active choice interventions create friction by requesting people to explicitly accept or decline an option. Hedlin and Sunstein (2016) showed that when participants were told that green energy was more expensive, active choosing was associated with a higher enrollment rate than the default condition. This is because active choosing induced a higher level of guilt among participants for not enrolling in green energy programs. In medical contexts, active choosing was shown to be more effective than a typical opt-in method in increasing advance directive completion among hospital employees (Josephs et al., 2018) and increasing the HIV test acceptance rate in patients (Montoy et al., 2016). Thus, requiring people to actively choose may be more effective in certain situations than defaults, especially when choice architects are hesitant in determining the best option for people (Sunstein, 2017).

Intrinsic motivation

Since people's intrinsic motivation varies over time, it is critical for choice architects to understand these fluctuations and decide the ideal circumstances to deliver an intervention that can either increase or decrease their motivation. Therefore, an intrinsic motivation intervention is defined as *an intervention that influences the inherent interests toward an option in the absence of external factors*. Nudge elicits people's inherent interest to engage in new behaviors, and sludge undermines people's inherent interests to deter them from undesirable behaviors.

This definition is derived from the self-determination theory which states that intrinsic motivation is defined as completing an activity to satisfy the innate psychological needs and fulfill the inherent interests of seeking novelty and challenges, without the influence of external rewards (Ryan & Deci, 2000). The theory suggests that three needs intrinsically motivate people: 1) autonomy, which refers to the freedom of choosing to complete an activity, 2) competence, which refers to the perceived ability or efficacy to complete an activity, and 3) relatedness, which refers to the feeling of connectedness to other people and community. It has been shown that factors that enhance or undermine one or more of these needs can increase or reduce a person's intrinsic motivation toward an activity. For example, directives from authorities, deadlines, or threats can reduce intrinsic motivation because people perceive these factors as controlling their behaviors and impairing their need for autonomy (Deci & Cascio, 1972).

Contrary to imposing directives, choice architects often ask people to set a goal and make a plan to enhance the feeling of autonomy, which can facilitate behavior change. However, the goal or the plan should be achievable to prevent undermining the need for competence. Choice architects have also developed self-control tools to increase the feeling of competence, commitment-making tools to enhance the need for autonomy and relatedness, and social norm

messaging to increase relatedness to the community. Empirical evidence for each intervention is discussed next.

Goal setting has been used as a beneficial intervention to turn intrinsic motivation into action by decreasing friction. A pioneering study showed that setting a specific and challenging but realistic goal (e.g., increasing sales by 10%) improved productivity among employees (Latham & Locke, 1979). This simple intervention induced the feeling of autonomy by involving employees in the goal-setting process and increased their need for competence by setting a realistic challenge, which effectively increased productivity. Goal setting has also been used to encourage body weight reduction (Pearson, 2012) and to promote pro-environmental behaviors (Staples et al., 2020).

In addition to goal setting, implementation intention is another beneficial friction-reducing intervention that requires people to develop specific plans on when, where, and how the goals can be achieved (Gollwitzer & Sheeran, 2006). A field experiment showed that employees who wrote down a specific date and time on their implementation intention card had a higher vaccination rate than those who only provided a date and those who only received a reminder (Milkman et al., 2011). Likewise, participants who specified the date, location, type of physical exercise, and the number of sweets to be consumed lost more weight than control participants (Luszczynska et al., 2007).

Another beneficial intervention that reduces friction is commitment-making defined as linking an individual's planned commitment to action (Kiesler, 1971). For example, after signing a pledge to recycle or save energy, people are more likely to follow through with their intended actions, especially when the pledges are made public (Pallak & Cummings, 1976; Vine & Jones, 2015). One explanation for the effectiveness of commitment-making is that people can

voluntarily choose to perform a behavior (e.g., whether to sign the pledge or not), and they are motivated to behave consistently with their intentions (Joule et al., 2007). Commitment-making has been frequently used to promote behaviors that are beneficial to the entire community, because people seek to enhance their relatedness to the community. Because commitment-making satisfies two intrinsic needs, its impact on behavior change has been shown to last for a long time (Cialdini, 2001). Based on the meta-analysis by Lokhorst et al. (2013), participants who made a commitment significantly increased their pro-environmental behaviors during the intervention period and post-intervention period, compared to the control condition. A recent study showed that people who made a commitment in addition to social normative information used less water compared to people who only received the social normative information (Jaeger & Schultz, 2017).

Social norm messaging has been used as an intervention that increases friction to trigger a reassessment of current behaviors based on the social norms with the intent to motivate people to adopt new behaviors that are beneficial for the community. Social norm messaging aims to increase intrinsic motivation by targeting the need for relatedness. A pioneering study showed that providing descriptive norm information of the average energy used by neighbors effectively reduced energy use among households that consumed more than average, but increased energy use among households that consumed less than average (Schultz et al., 2007). However, when injunctive norm information is provided, which shows approval from the community (e.g., a smiley face on an energy bill), households that consumed below average maintained their low baseline consumption level. The impact of normative messaging on energy conservation has been replicated with a larger sample (Allcott, 2011). In addition to energy conservation, social

norm messaging reduced alcohol consumption (Ridout & Campbell, 2014) and increased voting (Gerber & Rogers, 2009) when descriptive norm information was provided.

Self-control interventions are beneficial interventions that create friction to deter people from tempting but undesirable behaviors, and these strategies can boost people's feeling of competence (Frederick et al., 2002). One study proposed 32 self-control strategies to reduce unhealthy food consumption, for example, by avoiding snack hoarding (Poelman et al., 2014). Gamblers can self-ban from casinos or set deposit limits to reduce their gambling behaviors (Broda et al., 2008; Gainsbury, 2014). Given the difficulties in controlling temptations, retailers often use harmful friction-reducing interventions to undermine consumers' self-control strategies. Junk food advertising has long been used as a tool that increases the consumption of unhealthy food. An analysis showed that more than 80% of TV advertising spending was used to promotes fast food, sugary drinks, sweets, and unhealthy snacks (Harris et al., 2019). With the invention of electronic cigarettes, the promotion of vaping products may be harmful to non-smoking young people by inducing them to start vaping earlier. Since vaping is perceived as healthier than smoking, the perceived peer approval of vaping was significantly higher than smoking among teenagers (East et al., 2019). Creating this "positive" norm is harmful for young people who may be nudged to start to vape early. This norm can also be harmful and increase friction for those who want to quit smoking since it makes quiting harder by normalizing alternative products to cigarettes.

Extrinsic motivation

Extrinsic motivation intervention is defined as *an intervention that imposes external rewards or punishments to alter behaviors* in the current framework. Nudge here provides external incentives to facilitate desirable actions, and sludge imposes external punishments to

deter undesirable actions. Deci and Ryan (2000) defined extrinsic motivation as completing an activity to obtain external rewards or avoid punishments. To make a clear distinction from intrinsic motivation interventions, extrinsic motivation interventions do not include examples of behaviors that are driven by intrinsic rewards or punishment emanating from internal factors (e.g., personal expectations or goals). It is important to note that extrinsic motivation interventions use small external rewards or punishments that do not significantly change the incentive structure, and these interventions also do not forbid people from choosing other options (therefore a nudge). Below we review existing studies that used small external incentives or penalties to change behavior.

The most common extrinsic motivation intervention is to provide a small financial reward to encourage beneficial behavioral change (i.e., a beneficial intervention that reduces friction). In one study, participants who were paid a small incentive for attending the gym during one month showed a higher gym attendance rate than the control group who were not paid (Charness & Gneezy, 2009). A field experiment showed that providing small financial incentives to villagers increased their actual participation in communal tasks (Kerr et al., 2012). A meta-analysis showed that individual and team-based incentives were positively associated with work performance (Garbers & Konradt, 2014). In some studies, instead of paying a fixed amount of money to participants, incentives were used in form of lotteries where participants had a small chance to win a larger amount.

Imposing financial penalties (e.g., micro-tax) can discourage people from undesirable behaviors (i.e., a beneficial intervention that increases friction). A common intervention is imposing a small fee on plastic bags to reduce the quantity of plastic bags consumed at grocery stores. For example, when a $0.05 plastic bag fee was introduced in Toronto, Ontario from 2009

to 2012, the consumption of plastic bags was reduced by 53% in retail outlets, equating to an annual reduction of 240 million plastic bags (Solid Waste Management, 2013). In England, a five pence (≈$0.08) levy led to an 85% reduction in plastic bag usage in supermarkets (Xanthos & Walker, 2017). In Chicago, the average number of disposable plastic bags used per trip decreased by 40% after imposing a $0.07 tax on plastic bags (Homonoff et al., 2018). Moreover, charging a $0.25 tax per drink reduced alcohol consumption among U.S. adults who regularly consume alcohol (Daley et al., 2012).

Financial incentives can also be used as a harmful intervention that decreases friction to induce impulsive behaviors. For example, online gambling platforms offer sign-up incentives to attract gamblers. A longitudinal study showed that exposure to wagering inducements is associated with higher actual betting expenditure among gamblers (Browne et al., 2019).

Finally, sunk costs associated with an option can be a harmful intervention that increases friction by deterring consumers from choosing their intended option. Retailers tend to charge a membership fee to prevent customer attrition. If the membership fee is perceived as a sunk cost, it can create more friction for consumers who plan to terminate the membership and switch to other retailers. This example was supported by a virtual shopping experiment showing that after paying the membership fee at a store, consumers preferred the store more than others, even when the benefits associated with the store were removed (Dick, 1995).

Meta-analysis

We have thus far discussed the cognitive framework and provided examples of interventions targeting each of the six cognitive processes. As a critical empirical evaluation of the framework, we will examine the effect size of these interventions targeting each cognitive process by conducting a meta-analysis in the next section.

Past meta-analyses on nudge

There are several meta-analyses on nudge but they primarily focus on studies from the health sector. A recent meta-analysis (Cadario & Chandon, 2020) categorized healthy eating interventions into cognitively oriented interventions that influence consumers' knowledge (e.g., nutrition labeling), affectively oriented interventions that influence consumers' feeling (e.g., attractive graphics), and behaviorally oriented interventions that influence consumers' motor responses (e.g., ease to access healthy options). This meta-analysis examined field experiments that used a single intervention or mixed interventions defined as a combination of interventions, such as combining cognitively oriented interventions with behaviorally oriented ones. The results showed that behaviorally oriented interventions had the largest effect size.

Two additional meta-analyses examined interventions across multiple domains, such as health, environment, finances, energy, and policy-making (Beshears & Kosowsky, 2020; Hummel & Maedche, 2019). The meta-analyses included field experiments, lab experiments, online experiments, and surveys. Hummel and Maedche (2019) categorized interventions that were implemented in a conventional setting or a digital setting (e.g., a reminder email). Although there was no significant difference between the effectiveness of conventional nudge and digital nudge, they found that default had a larger effect size than the other interventions. Similarly, Beshears and Kosowsky (2020) found that interventions that used automaticity had a larger effect size than those that did not use automaticity.

The existing meta-analyses on nudge had several limitations. One limitation is that the analysis was restricted within a single domain and therefore limits the generalizability across domains. Another limitation is that the analysis included mixed interventions that combined different interventions in a single condition which makes it impossible to identify the impact of a

given intervention. A third limitation is the inclusion of a mixture of results from self-reported, lab studies, and field experiments. Mixing different methodologies in a single analysis means that there may be inconsistencies in the measures and contexts of the studies, since self-reported behaviors do not always align with actual behaviors (Barker et al., 1994; (Gatersleben et al., 2002), and lab settings are more constrained and artificial than field settings which may produce inconsistent behavioral results. A fourth limitation is that past meta-analyses mixed the results of quasi-experiments with randomized controlled trials, which makes it difficult to identify the causal factor. A final limitation is that past meta-analyses did not separate interventions that reduce or increase friction and therefore cannot explain the difference in the impact of interventions that increase decision friction from those that decrease friction. To address these limitations, we have conducted a meta-analysis with only field experiments (randomized controlled trials) with actual behavioral measures instead of self-reports to examine the effectiveness of interventions targeting each of the six cognitive processes outlined in the cognitive framework.

Methods

All of the data and code of the meta-analysis are available here: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/RN1YJX To create the data set, we conducted a literature search in seven databases across multiple disciplines: Web of Science, PubMed, PsychInfo, Business Source Ultimate, PsychExtra, Google Scholar, and Proquest. The last two databases were used to include grey literature, such as non-academic articles, business reports, and unpublished dissertations. The first search term was “nudge,” “nudging,” “sludge,” or “sludging,” and the second joint search term was “randomized controlled trial”. Given the large number of search results on Google Scholar, the second term

was changed to “field” to limit the number of articles. Moreover, disciplines such as physics and meteorology that use the term nudge and sludge based on other definitions were excluded from the search. The publication year was restricted from 2008 to 2020 as the term nudge was popularized after the publication of the book *Nudge* in 2008 (Thaler & Sunstein, 2008).

After removing duplicates from the initial search, we conducted an analysis of the titles and abstracts to exclude review articles or studies reporting qualitative data. In the full-text assessment stage, articles were selected based on four criteria: field experiments, single interventions, randomized controlled trials, and actual behavioral measures. Articles that tested multiple single interventions in separate conditions were included as distinct observations. Articles that used mixed interventions (e.g., reminders with norm messaging) in one condition were excluded from the analysis. Actual behavioral measures were defined as objective measures of behaviors (e.g., actual percent change in energy consumption) rather than self-reported behaviors. In total, n=179 articles met all four criteria, k=222 observations, and N=4,440,011 participants were included in the meta-analysis (see details of the selected articles in Supplementary Materials). Figure 1 presents the PRISMA flow diagram showing the four stages of article selection with the number of articles at each stage.

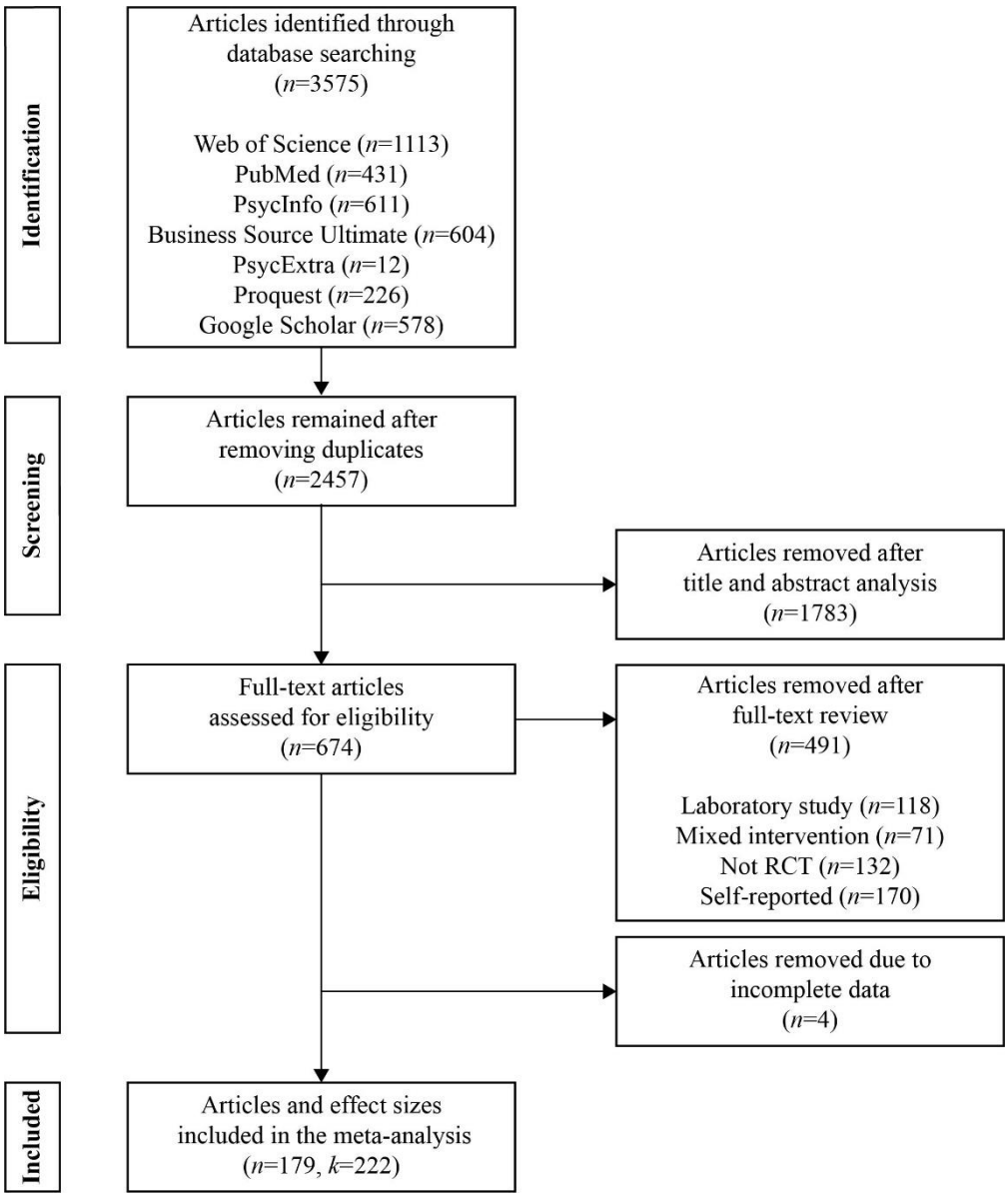

Figure 1. A PRISMA flow diagram showing the four stages of article selection with the number of articles in each stage.

Since we did not limit our search to a specific discipline, studies from education, environment, finance, health, and policy-making sectors were included in the meta-analysis. By analyzing the number of articles published per year among the articles included in the meta-analysis, more articles were published in the last four years (2017-2020), showing an increased

interest in examining the effect of nudge and sludge on actual behavior change in field experiments (Figure 2).

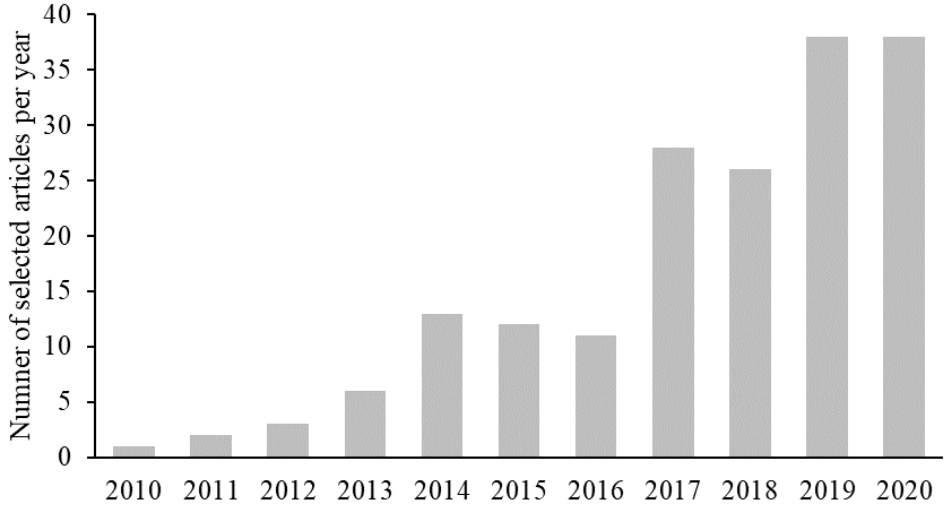

Figure 2. The number of selected articles per year in the meta-analysis.

The 222 observations were further categorized into one of the six cognitive processes based on the definitions discussed in the cognitive framework. Two coders independently categorized each intervention into one of the six cognitive processes and there was a 95% agreement among the coders. Each intervention was classified as nudge or sludge, depending on whether the intervention increased or decreased decision friction, and whether the intervention was beneficial or harmful. Since very few articles on harmful nudge (n=3) or sludge (n=1) were published due to ethical concerns of these interventions or the unavailability of data from firms that use harmful nudge or sludge, a comparison between beneficial and harmful interventions was not feasible. Since different studies used different outcome measures, we converted the effect sizes following the guidelines provided by Harrer et al (2019). Specifically, we converted the mean difference between the treatment condition and the control condition to Cohen's d by dividing the pooled standard deviation for continuous variables. If a study did not provide

sufficient information on the means, standard deviations, and sample sizes, the raw data were requested and obtained, and manually analyzed to obtain the relevant statistics. Studies that failed to report the complete set of statistics and did not provide the raw data were excluded. When studies used dichotomous variables, the odds ratio was computed and then converted to Cohen's *d*. Several studies used dummy coding for the dichotomous variable and reported the relative difference between the treatment condition and the control condition, and the relative difference was converted to Cohen's *d*. Several studies reported a raw comparison between the treatment condition and the control condition, and additional comparisons after controlling for covariates. To minimize biases in the results, only comparisons without controlling for covariates were included in the meta-analysis. Moreover, some observed reductions in undesirable behaviors (e.g., reduced water consumption) were coded as positive although the original effect size was negative.

Results and Discussion

After pooling the effect sizes using the random-effects model, the overall effect size was 0.30 (Cohen's *d*) from the meta-analysis. Interventions that reduce friction (*k*=178) had an average effect size of 0.31 and interventions that increase friction (*k*=44) had an average effect size of 0.20. Across the six cognitive processes (Table 3), effort interventions had the largest effect size (*d* = 0.58), followed by attention interventions (*d* = 0.32), extrinsic motivation interventions (*d* = 0.31), perception interventions (*d* = 0.30), memory interventions (*d* = 0.29), and intrinsic motivation interventions (*d* = 0.13).

Table 3: Effect size (Cohen's *d*) of interventions that reduce friction (here, nudge) or increase friction (here, sludge) by cognitive processes

Cognitive process	**Type**	***k***	***d* [95% CI]**	**Combined *d* [95% CI]**
Attention	Nudge	16	0.34 [0.05, 0.64]	0.32 [0.08,0.56]

	Sludge	4	0.14 [-0.41, 0.70]	
Perception	Nudge	39	0.31 [0.17, 0.45]	0.30 [0.18, 0.41]
	Sludge	10	0.25 [0.03, 0.47]	
Memory	Nudge	41	0.29 [0.14, 0.43]	0.29 [0.14, 0.43]
	Sludge	2	0.32 [0.24., 0.40]	
Effort	Nudge	27	0.61 [0.38, 0.85]	0.58 [0.39, 0.77]
	Sludge	8	0.44 [0.08, 0.80]	
Intrinsic motivation	Nudge	37	0.15 [0.08, 0.23]	0.13 [0.07, 0.18]
	Sludge	16	0.07 [0.01, 0.12]	
Extrinsic motivation	Nudge	18	0.32 [0.16, 0.47]	0.31 [0.17, 0.44]
	Sludge	4	0.28 [-0.22, 0.79]	
Overall	Nudge	178	0.33 [0.26, 0.39]	0.30 [0.25, 0.36]
	Sludge	44	0.20 [0.12, 0.29]	

To test the difference in effect sizes across the six cognitive processes, a 2 (intervention type: nudge and sludge) × 6 (cognitive process: attention, perception, memory, effort, intrinsic motivation, and extrinsic motivation) ANOVA was conducted. The analysis revealed a main effect of cognitive process [$F(5, 210) = 3.84$, $p = .002$, $\eta_p^2 = .08$] but no main effect of intervention type [$F(1, 210) = 0.31$, $p = .23$, $\eta_p^2 = .006$] and no interaction between intervention type and cognitive process [$F(5, 210) = 0.04$, $p = .99$, $\eta_p^2 < .001$]. Post-hoc Tukey's HSD tests were subsequently conducted to reveal that the only significant pairwise difference was that the effort interventions had significantly larger effect sizes than intrinsic motivation interventions ($p < .001$; Figure 3).

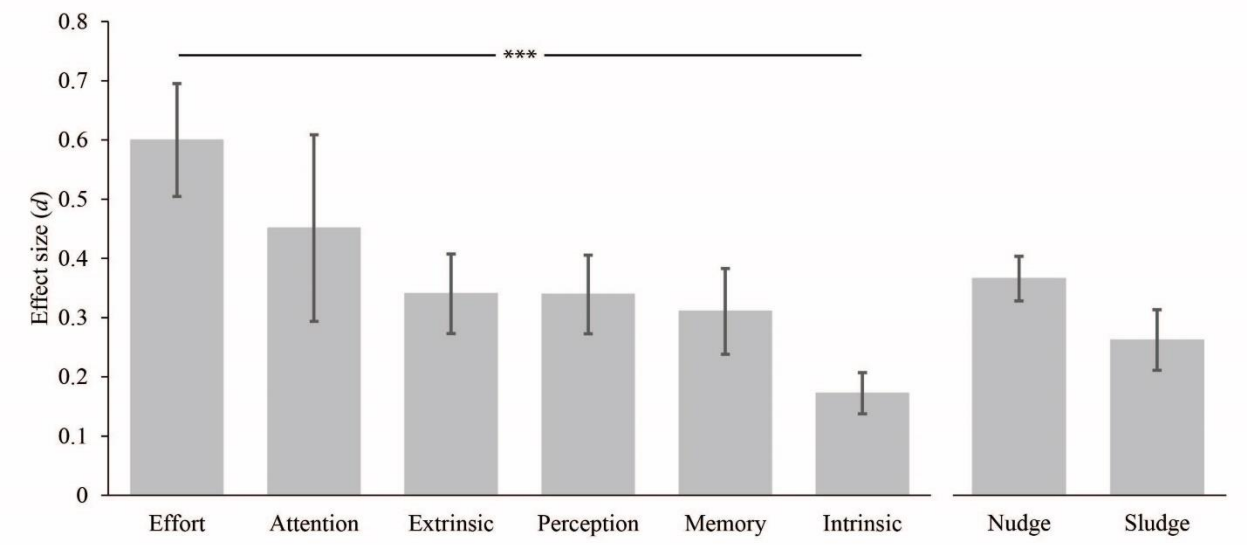

Figure 3. One-way ANOVA and post-hoc Tukey's HSD results (***p<.001, error bars mean 1±SE).

To examine which specific intervention had the largest effect size, we conducted a one-way ANOVA on the common interventions that had at least two observations in the meta-analysis. The reason we included interventions that had at least two observations was because a minimum of two data points per intervention was required to conduct the ANOVA tests (see Table 4). There was a significant difference between the common interventions [F(33, 188) = 1.76, p = .01, η_p^2 = .24]. Post-hoc Tukey's HSD tests revealed that the default intervention had a marginally higher effect size than social norms interventions (p = .06) and all the other comparisons were not significant (p's > .11).

Tabl4 shows that interventions that reduced effort by making an option more convenient (d = 1.18) had the largest effect size in the effort category. Highlighting important information (d = 0.57), rewarding with non-financial incentives (e.g., stamps with smiley faces, d = 0.41), changing the appearance of an option (d = 0.74), using anchors (d = 0.78), and making a commitment (d = 0.29) were the most effective interventions targeting attention, extrinsic motivation, perception, memory, and intrinsic motivation, respectively.

Table 4. Effect size of common interventions

Intervention	**Cognitive process**	***k* (>1)**	***d* [95% CI]**
Convenience	Effort	3	1.18 [-0.38, 2.74]
Anchoring	Memory	2	0.78 [-8.51, 10.07]
Appearance	Perception	3	0.74 [-0.86, 2.33]
Default	Effort	13	0.73 [0.32, 1.13]
Inconvenience	Effort	5	0.71 [0.28, 1.14]
Informational feedback	Perception	5	0.59 [0.31, 0.87]
Highlighting	Attention	7	0.57 [-0.22, 1.36]
Non-financial incentives	Extrinsic	5	0.41 [0.01, 0.81]
Accessibility	Effort	8	0.40 [0.18, 0.62]
Conditional incentives	Extrinsic	3	0.39 [-0.35, 1.14]
Informational messaging	Perception	10	0.38 [0.08, 0.69]
Availability	Perception	5	0.36 [-0.36, 1.08]
Reminder	Memory	32	0.29 [0.13, 0.46]
Commitment making	Intrinsic	6	0.29 [-0.05, 0.63]
Gain framing	Perception	11	0.28 [-0.03, 0.58]
Financial incentives	Extrinsic	13	0.28 [0.09, 0.47]
Goal setting	Intrinsic	3	0.22 [-0.05, 0.50]
Visibility	Attention	9	0.20 [-0.04, 0.43]
Priming	Memory	9	0.17 [-0.10, 0.44]
Graphics	Perception	4	0.16 [-0.25, 0.56]
Social norm	Intrinsic	33	0.11 [0.04, 0.18]
Motivational intervention	Intrinsic	5	0.11 [-0.01, 0.24]
Active choice	Effort	3	0.11 [-0.16, 0.37]
Simplification	Effort	3	0.07 [-0.10, 0.23]
Loss framing	Perception	5	0.05 [-0.01, 0.11]
Implementation intention	Intrinsic	5	0.03 [-0.02, 0.09]
Assortment size	Perception	5	0.03 [-0.19, 0.25]

To examine publication bias in the meta-analysis, we performed a p-curve analysis. Specifically, a right-skewed *p*-value distribution (i.e., more studies with *p*s less than .025 than *p*s between .025 and .05) indicates the existence of a true effect, and a uniform distribution suggests a nonexistent effect (Simonsohn et al., 2014). Among the significant findings, a right-skewed *p*-

curve with 84% of the *p*-values being less than .025 was observed, suggesting that the set of studies included in the meta-analysis exhibited a robust effect of interventions on behavioral change, and therefore no evidence of publication bias was found.

General Discussion

The goal of the current paper was to generate a new cognitive framework to categorize interventions that reduce or increase decision friction based on six underlying cognitive processes and examine the effect size of interventions targeting each cognitive process. In the first part of the review, we proposed a cognitive framework of nudge and sludge to explain how interventions target specific cognitive processes to change behaviors. For example, an attention intervention that reduces friction aimed to increase the salience of an option (e.g., highlighting), and an attention intervention that increases friction was designed to create a decision point (e.g., warnings) to deter people from undesirable behaviors (e.g., smoking).

This cognitive framework builds upon the categories in the MINDSPACE framework. Specifically, effort, memory, and perception interventions in the current framework provide more comprehensive guidelines to organize interventions that reduce friction than the default, priming, affect, and messenger categories in MINDSPACE. For example, effort interventions include not only default but also interventions manipulating the degree of convenience. Memory interventions contain reminders in addition to priming, and perception interventions extend to informational and real-time feedback. Therefore, the current cognitive framework can provide additional theoretical insights on how interventions that reduce or increase friction can be categorized along the cognitive dimension.

The current cognitive framework also provides new useful guidelines to choice architects in terms of how to choose interventions based on the demonstrated impact. MINDSPACE is a

frequently used framework, but the authors claimed that the ordering of the nine categories in the acronym was not meaningful (Dolan et al., 2012). According to the results of the current meta-analysis, the nine categories can be ordered based on the effectiveness of the interventions. Choice architects should consider default (effort) as their first intervention, then salience (attention), incentives (extrinsic motivation), messengers and affect (perception), and priming (memory), and lastly ego, commitment, and norms (intrinsic motivation) interventions. Likewise, the EAST framework recommends four principles on how to design effective interventions, but it only stressed the importance of making an option easy for people, without providing an ordering for the other three principles. According to the current meta-analysis, interventions aimed to reduce effort were the most effective interventions. Making an option attractive should be the second most effective because this principle focuses on how to attract people's attention. Making an option timely will be the third most effective since it targets people's memory. Finally, making an option social will be the least effective since interventions targeted intrinsic motivation which was less effective than other interventions.

Another important feature of the current framework is the separation of interventions that are beneficial to people and those that are harmful. Because academic research has exclusively focused on beneficial interventions, harmful interventions tend to be in the gray literature and are often neglected in the discussion of nudge. The current framework aims to capture both beneficial and harmful interventions and expand existing knowledge on which interventions can negatively affect people's welfare.

In the second part of the review, a meta-analysis showed an overall positive effect of interventions on behavior change. The analysis also showed that the interventions that targeted effort (e.g., convenience) had the largest effect size. This finding was supported by previous

meta-analyses that demonstrated default and automaticity interventions were the most effective (Beshears & Kosowsky, 2020; Hummel & Maedche, 2019). Interventions targeting intrinsic motivation (e.g., goal setting, implementation intention, social norms) had the smallest effect size. The effect size of intrinsic motivation interventions was similar to the findings of a meta-analysis of randomized controlled trials on pro-environmental behaviors (Nisa et al., 2019). Moreover, the impacts of the two types of interventions were not significantly different, suggesting that interventions that reduce decision friction and those that increase friction had similar efficacy in behavior change. However, the sample size of interventions that increase friction was considerably smaller (k=44) than interventions that reduce friction (k=178), suggesting that the effect size of interventions that increase friction should be interpreted with caution. This also calls for the need to examine more future interventions that increase friction.

This new meta-analytic cognitive framework has several theoretical, empirical, and practical contributions. First, it provides cognitive insights on nudge and sludge by explaining how the intervention targets the specific cognitive process to change behavior. Second, the framework allows comparisons of impact between interventions that target different cognitive processes. For example, reducing effort by using default was more impactful in achieving behavior change than increasing intrinsic motivation by using social norm messaging. Third, the meta-analysis excluded self-reported data and laboratory studies, permitting comparisons using consistent behavioral measures and contexts. Fourth, since only randomized controlled trials were included in the analysis, the effect of the interventions should demonstrate a causal impact of the interventions on behavior change. Finally, the framework offers a ranking of interventions based on cognitive processes and the associated behavioral impact, which can guide the development of future interventions.

Although the theoretical, empirical, and practical contributions of the current review are prominent, the current framework has some limitations. First, the categorization of the interventions based on the cognitive processes and nudge/sludge, benefit-harm dimensions was subjective. Future studies can seek further support for the categorization with empirical data, for example, by inviting other researchers who are familiar with cognitive concepts to classify the interventions based on the definitions discussed in the current review. The consensus among these experts will reduce the subjectivity of this cognitive framework. Second, in the meta-analysis, 91% of the selected studies were conducted in developed countries which limits the generalizability of the effects of nudge and sludge to developing countries. Finally, the number of published studies on harmful nudge (n=3) and sludge (n=1) is small, which restricted comparisons between beneficial and harmful interventions. Moreover, the number of interventions that increase friction is scarce in the literature. Given the limited number of observations, the effect sizes of these interventions need to be interpreted with caution.

In conclusion, the current meta-analytic cognitive framework provides new insights on how nudge and sludge can be categorized based on cognitive dimensions and it also demonstrates the effectiveness of the interventions targeting each cognitive process. This review paper can help inform the development of future interventions and improve the impact of these interventions by targeting effort or attention mechanisms.

Acknowledgments

We thank Luke Clark and Todd Handy for providing helpful comments. This work was supported by the Canada Research Chairs program (to DS and JZ), Social Sciences and Humanities Research Council (SSHRC) Doctoral Fellowship (to YL), the SSHRC Partnership Grant (DS and JZ), and a grant from Environment and Climate Change Canada (GCXE21E006 to JZ and YL).

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Supplementary Materials

Legend of Table S1:

Category:

1st letter represents whether the intervention is beneficial or harmful:

B = beneficial, H = harmful

2nd letter represents the type of intervention:

N = nudge, S = sludge

3rd letter represents the cognitive process:

At = attention, Pe = perception, Me = memory, Ef = effort, In = Intrinsic motivation, Ex = extrinsic motivation

Length:

The duration of the interventions is shown in the number of months. Zero indicates a one-time intervention.

Data:

b = unstandardized regression coefficient

beta = standardized regression coefficient

OR = odds ratio

BP = binary proportions

2x2 = 2 by 2 frequency table

M&SD = mean and standard deviation

MG&SD = mean gain scores and standard deviations

M&SE = mean and standard error

t = *t*-test

F = one-way ANOVA with two independent groups

Table S1: Complete list of studies in the meta-analysis

Author	Category	Intervention	Behavioral measure	Length	Location	Data
Ahomaki et al. (2020)	B_N_Pe	Informational messaging	Opioid prescribing rate	0	Finland	b
Allan & Powell (2020)	B_N_Me	Reminder	Reduction in the calorie content of purchased items	3	UK	b
Altmann & Traxler (2014)	B_N_Me	Reminder	Dental check-up appointment	0	Germany	BP
Andor et al. (2020)	B_S_In	Social norm	Electricity consumption	6	Germany	b
Araña & León (2013)	B_N_Ef	Default	Carbon offsetting purchase	0	Gran Canaria	BP
Avdeenko et al. (2019	B_N_In	Goal setting	Amount of savings	12	Ethiopia	b
Ayala et al. (2017)	B_N_At	Highlighting	Weekly number of healthy items sold	2	US	b
Baca-Motes et al. (2013)	B_N_In	Commitment making	Towel reuse	0	US	BP
Baggio & Motterlini (2019	B_N_Me	Anchoring	Amount of donation	0	Italy	M&SD
Baker et al. (2016)	B_N_In	Implementation intention	Watch lecture video	0	US	BP
Bartke et al. (2017, descriptive)	B_N_In	Social norm	Number of donations	0	Germany	BP
Bartke et al. (2017, guess)	B_N_In	Social norm	Number of donations	0	Germany	BP
Bateson et al. (2015)	B_N_Me	Priming	Percent of cyclists littered	0	UK	2x2
Bauer et al. (2019)	B_N_In	Social norm	Click on resource link	0	US	2x2
Bennion & Nickerson (2021)	B_N_Ef	Convenience	Voter registration	0	US	BP
Bergh et al. (2019)	B_N_Me	Reminder	Voter turnout	0.25	Norway	b
Bernedo et al. (2014)	B_S_In	Social norm	Water consumption (gallons)	0	US	b

Bertoni et al. (2020)	B_N_Pe	Loss framing	Screening take-up	0	US	BP
Bhatti et al. (2015, traditional vs. control)	B_N_Pe	Gain framing	Turnout rate	0	Denmark	BP
Bhatti et al. (2015, vivid vs. control)	B_N_Pe	Graphic	Turnout rate	0	Denmark	BP
Biddle et al. (2018, color)	B_N_At	Highlighting	Tax payment rate	0	US	b
Biddle et al. (2018, norm)	B_N_In	Social norm	Tax payment rate	0	US	b
Biswas et al. (2017)	B_N_Me	Priming	Healthy food choice	0	US	BP
Blaehr et al. (2018)	B_S_Ex	Fine	Non-attendance rate	0	Denmark	2x2
Bollinger et al. (2020, prosocial vs. control)	B_N_In	Social norm	Rooftop solar PV installation	12	US	t
Bollinger et al. (2020, self-interest vs. control)	B_N_Pe	Gain framing	Rooftop solar PV installation	12	US	t
Bracha & Meier (2015)	B_N_Me	Reminder	Average change in credit score	12	US	M&SD
Bradley et al. (2018)	B_N_Ex	Financial incentives	Number of visits to primary care provider	6	US	M&SE
Brandon et al. (2019)	B_S_In	Social norm	Electricity consumption at peak hours	2	US	b
Brannan (2012)	B_S_Pe	Informational feedback	Fuel economy (miles per gallon)	0.5	US	b
Brent et al. (2020)	B_S_In	Social norm	Percent of water consumption	2	US	b
Bronchetti et al. (2013)	B_N_Ef	Default	Savings bond participation rate	2	US	b
Bronchetti et al. (2015,	B_N_Me	Priming	Flu vaccine take-up	2	US	BP

coughing vs. control)						
Bronchetti et al. (2015, incentive vs. control)	B_N_Ex	Financial incentives	Flu vaccine take-up	2	US	BP
Bronchetti et al. (2015, peer vs. control)	B_N_In	Social norm	Flu vaccine take-up	2	US	BP
Brune et al. (2017)	B_N_Ef	Default	Amount of savings	1	Malawi	b
Bucher et al. (2014)	B_N_Pe	Availability	Total energy from vegetables	0	Switzerland	M&SD
Bulte et al. (2020	B_S_Ex	Conditional incentives	Number of folded envelopes	0	Uganda	M&SD
Byerly et al. (2019)	B_N_In	Social norm	Number of owners requested more information on the conservation program	3	US	BP
Campbell-Arvai et al. (2014) (default)	B_N_Ef	Default	Choice of meat-free meal	0.5	US	2x2
Campbell-Arvai et al. (2014) (information only)	B_N_Pe	Graphic	Choice of meat-free meal	0.5	US	2x2
Capraro et al. (2019, study 5)	B_N_In	Motivational intervention	Amount of donation	0	US	M&SD
Carpena et al. (2019)	B_N_Ex	Financial incentives	Financial numeracy scores	1.25	India	b
Carrera et al. (2018)	B_N_In	Implementation intention	Total gym visits	0.5	US	b
Castleman & Page (2015)	B_N_Me	Reminder	College enrollment	4	US	b
Castleman & Page (2016)	B_N_Me	Reminder	College enrollment persistence	8	US	BP

Chareyron et al. (2018, highlighted)	B_N_At	Highlighting	Social assistance benefits take-up	6	France	b
Chareyron et al. (2018, simplified)	B_N_Ef	Simplification	Social assistance benefits take-up	6	France	b
Chirico et al. (2019 reminder only vs. control)	B_N_Me	Reminder	Tax compliance (full payment)	0	US	BP
Chirico et al. (2019, reminder only vs. reminder+social norm)	B_S_In	Social norm	Tax compliance (full payment)	0	US	BP
Chirico et al. (2019, reminder only vs. reminder+treat)	B_S_Pe	Loss framing	Tax compliance (full payment)	0	US	BP
Clark et al. (2014)	B_N_Pe	Informational messaging	Retirement plan registration	0	US	BP
Coffino et al. (2020)	B_N_Ef	Default	Servings of healthy food	0	US	M&SE
Costa & Kahn (2013)	B_S_In	Social norm	Electricity consumption	0	US	b
Cotterill et al. (2013)	B_N_In	Commitment making	Percent of household donated a book	0	UK	M&SE
Coucke et al. (2019)	B_N_Pe	Availability	Sales of poultry products	1	US	M&SD
Courtright et al. (2017)	B_N_Pe	Availability	Advance directives completion rate	0	US	BP
Crago et al. (2020)	B_S_Pe	Informational feedback	Electricity consumption	1	US	M&SD
Cranor et al. (2020, norm)	B_S_In	social norm	Tax payment rate	0	US	BP
Cranor et al. (2020, penalty)	B_S_Pe	Loss framing	Tax payment rate	0	US	BP

Dallas et al. (2019)	B_N_At	Visibility	Lower calories food choice	0	US	M&SD
Dalrymple et al. (2020)	B_N_Ef	Default	Selection of lower-energy-dense items	0.25	US	2x2
Damgaard & Gravert (2018)	B_N_Me	Reminder	Number of people donated	0.25	Denmark	BP
de Wijk et al. (2016)	B_N_Ef	Accessibility	Whole wheat bread sales	2	Netherlands	2x2
Didero (2019)	B_N_Pe	Graphic	Coupon redemption rate	5	US	BP
dos Santos et al. (2018)	B_N_At	Highlighting	Meal choice	4	Denmark.	2x2
Dur et al. (2019)	B_N_In	Social norm	Amount of savings	0	Netherlands	b
Earnhart & Ferraro (2020)	B_S_In	Social norm	Wastewater discharge ratio	0	US	b
Ebeling & Lotz (2015)	B_N_Ef	Default	Percent of consumers purchased green energy	1	Germany	BP
Eguino et al. (2020, request vs. control)	B_N_Pe	Informational messaging	Online tax registration	1	Brazil	BP
Engstrom et al. (2019)	B_N_Pe	Informational messaging	Housing allowance application	0	Sweden	BP
Eskreis-Winkler et al. (2019, math)	B_N_In	Motivational intervantion	Math class grades	1	US	M&SD
Eskreis-Winkler et al. (2019, target)	B_N_In	Motivational intervantion	Target class grades	1	US	M&SD
Ferman (2016)	H_S_At	Visibility	Credit card take-up	0	Brazil	2x2
Figueroa et al. (2019)	B_N_Ex	Financial incentives	CFL uptake	1.25	Kenya	b
Fox et al. (2019 (study 1)	B_S_Ef	Inconvenience	Number of napkin per person	3	US	t

Friis et al. (2017, default)	B_N_Ef	Default	Vegetable consumption	0	Denmark	M&SD
Friis et al. (2017, priming)	B_N_Me	Priming	Vegetable consumption	0	Denmark	M&SD
Friis et al. (2017, variety)	B_N_Pe	Portion size	Vegetable consumption	0	Denmark	M&SD
Gallus (2017)	B_N_Ex	Non-financial incentives	Retention rate	11	Online	BP
Garnett et al. (2019)	B_N_Pe	Availability	Vegetarian meal sale	0	US	BP
Ghose et al. (2019)	B_N_Ef	Accessibility	Coupon redemption rate	0	US	BP
Gillitzer & Sinning (2019)	B_N_Me	Reminder	Tax payment rate	0	Australia	b
Gold et al. (2019)	B_N_Pe	Gain framing	Number of patients who attended an NHS health check	6	US	2x2
Gold et al. (2019)	B_N_Pe	Loss framing	Number of patients who attended an NHS health check	6	US	2x2
Goldin et al. (2020, baseline vs. control)	B_N_Me	Reminder	Enrollment in Thrift Savings Plan	0	US	BP
Goldin et al. (2020, special vs. baseline)	B_N_At	Highlighting	Enrollment in Thrift Savings Plan	0	US	BP
Grieco et al. (2018, Info)	B_N_Pe	Gain framing	Consent to donate cord blood	0	Canada	2x2
Grieco et al. (2018, Info+choice)	B_S_Ef	Active choice	Consent to donate cord blood	0	Canada	2x2
Grinstein-Weiss et al. (2017, exp1:	B_N_Pe	Gain framing	Tax saving choice	0	US	BP

emergency vs. control)						
Gupta et al. (2016)	B_N_Ex	Financial incentives	Colorectal cancer screening uptake	0	US	2x2
Gwozdz et al. (2020)	B_N_Ex	Non-financial incentives	Vegetable consumption	0	US	M&SD
Hainmueller et al. (2018, call)	B_N_Me	Reminder	Naturalization application rate	0	US	BP
Hainmueller et al. (2018, letter)	B_N_Me	Reminder	Naturalization application rate	0	US	BP
Hainmueller et al. (2018, SMS)	B_N_Me	Reminder	Naturalization application rate	0	US	BP
Hainmueller et al. (2018, voucher)	B_N_Ex	Financial incentives	Naturalization application rate	0	US	BP
Hansen et al. (2019)	B_N_Ef	Default	Vegetarian meal choice	0	Denmark	2x2
Hirst et al. (2017)	B_N_Me	Reminder	Colorectal cancer screening uptake	2	UK	BP
Hogberg et al. (2020, study1)	H_N_Ex	Financial incentives	Move tourists to a location	0	Norway	2x2
Hogberg et al. (2020, study2)	H_N_Me	Priming	Move tourists to a location	0	Norway	2x2
Hou (2015)	H_N_In	Social norm	Number of cookies ordered	0	US	F
Hou (2017)	B_N_Me	Anchoring	Number of cookies ordered	0	US	M&SD
Huang et al. (2019)	B_N_At	Visibility	Online registration rate	0	US	BP
Huf et al. (2020)	B_N_Me	Reminder	Cervical screening uptake	3.75	UK	BP
Inkelaar & Simpson (2015)	B_N_In	Motivational intervention	Distant education retention rate	0	UK	BP
Jakobsen & Serritzlew (2016)	B_N_Pe	Informational messaging	Knowledge test	0	Denmark	BP
Jespersen (2018)	B_S_In	Social norm	Litigation in consumer disputes	0	Denmark	2x2

John & Blume (2017, collective)	B_N_Pe	Gain framing	Usage of online service	4	UK	BP
John & Blume (2017, simplified)	B_N_Ef	Simplification	Usage of online service	4	UK	BP
Joo et al. (2018, commitment)	B_N_In	Commitment making	Water consumption	0	Korea	M&SD
Joo et al. (2018, reminder)	B_S_Me	Reminder	Water consumption	0	Korea	M&SD
Joo et al. (2018, social)	B_S_In	Social norm	Water consumption	0	Korea	M&SD
Júdice et al. (2015)	B_S_At	Alert	Sitting time (hr)	4	Portugal	M&SD
Kallbekken & Saelen (2013, sign vs. control)	B_S_Me	Reminder	Reduce food waste	2	Norway	MG&SD
Kallbekken & Saelen (2013, size vs. control)	B_N_Pe	Portion size	Reduce food waste		Norway	MG&SD
Kanchanachitra et al. (2020)	B_S_Ef	Inconvenience	Fish sauce consumption	1.25	Thailand	M&SD
Kažukauskas et al. (2017, electricity)	B_S_In	Social norm	Electricity consumption	12	Sweden	MG&SD
Kažukauskas et al. (2017, water)	B_S_In	Social norm	Water consumption	12	Sweden	MG&SD
Keller et al. (2015)	B_N_Ef	Accessibility	Healthy snack choice	0	Switzerland	2x2
Kersbergen et al. (2018)	B_S_Pe	Portion size	Alcohol consumption	0	UK	M&SD
Kettle et al. (2017,	B_N_In	Social norm	Tax liability declared	0	Guatemala	b

public good vs. control)						
Kettle et al. (2017, self-select vs. control)	B_N_Me	Priming	Tax liability declared	0	Guatemala	b
Kettle et al. (2017, sign vs. control)	B_N_In	Commitment making	Tax liability declared	0	Guatemala	b
King et al. (2016)	B_N_Me	Priming	Number of people who used hand hygiene	3	UK	2x2
Knowles et al. (2020, study 1)	B_N_Ef	Accessibility	Food consumption	0	US	M&SD
Knowles et al. (2020, study 2)	B_N_Pe	Appearance	Food consumption	0	US	M&SD
Kongsbak et al. (2016)	B_N_Ef	Accessibility	Fruit and vegetable consumption (g)	0	Denmark	M&SD
Kosite et al. (2019)	B_S_Pe	Portion size	Calories consumption	0	UK	M&SD
Kristal & Whillans (2020, study 1)	B_N_In	Social norm	Carpooling registration	2	US	M&SD
Kristal & Whillans (2020, study 3a)	B_N_Ex	Financial incentives	Purchase of subsidized transit cards	3	US	2x2
Kristal et al. (2020)	B_N_At	Visibility	Percent of people cheating	0	US	t
Kroese et al. (2016)	B_N_Ef	Accessibility	Healthy snack purchase	0.25	Netherlands	2x2
Kurz (2018)	B_N_At	Highlighting	Vegetarian meal sale	4.25	Sweden	M&SE
Larkin et al. (2018, norm)	B_N_In	Social norm	Tax payment rate	0	UK	BP
Larkin et al. (2018, salience)	B_N_At	Highlighting	Tax payment rate	0	UK	BP
Lattarulo et al. (2017)	B_N_Ex	Non-financial incentives	Museum visit	0	Italy	BP

Lesner & Rasmussen (2014, identifiable vs. neutral)	B_N_Pe	Identifiable victim	Amount of donation	0	Denmark	M&SD
Libotte et al. (2014)	B_S_Pe	Portion size	Total energy meal (kj)	0	US	M&SD
Lieberoth et al. (2018)	B_N_Me	Reminder	Number of transit card uses	1	Denmark	M&SD
Liebig & Rommel (2014)	B_N_Ef	Default	Attached sticker on mailbox	2	Germany	2x2
Linos et al. (2020, study 2)	B_N_Ef	Simplification	Compliance	11	US	BP
List & Samek (2017)	B_N_Ex	Non-financial incentives	White milk choice	5 days	US	b
Lott (2017)	B_S_In	Social norm	Percent of water consumption	5	US	b
Luo et al. (2019)	B_N_Pe	Loss framing	Online purchase decision	1	Asia	b
Marx & Turner (2019)	B_N_Ex	Financial incentives	Student loan uptake	0	US	BP
Marzilli Ericson et al. (2017)	B_N_Pe	Gain framing	Switch health insurance plan	2	US	BP
McCrackin (2012)	B_N_Ex	Financial incentives	Garden dimension	0	US	MG&SD
Meeker et al. (2014)	B_N_In	Commitment making	Inappropriate antibiotic prescription	3	US	BP
Mikkelsen & Quinto Romani (2017)	B_S_Ef	Inconvenience	Number of butter packs consumed	0	Denmark	2x2
Milkman et al. (2011)	B_N_In	Implementation intention	Number of vaccinated employees	0	US	2x2
Miller et al. (2016)	B_N_Pe	Informational feedback	Number of meals contained healthy food	0.5	US	BP
Missbach & König (2016)	B_N_At	Visibility	Healthy food choice	0	Austria	2x2

Mors et al. (2018)	B_N_Me	Priming	Food choice	0	Netherlands	2x2
Moseley & Stoker (2015)	B_N_Ef	Default	Actual organ donor registration	0	UK	2x2
Moseley et al. (2018)	B_N_In	Social norm	Volunteering hours	1	US	MG&SD
Mundt et al. (2020)	B_S_Ef	Inconvenience	Straw consumption	0	Germany	2x2
Myers & Souza (2020)	B_S_In	Social norm	Energy conservation	4	US	b
Namazu et al. (2019, location A)	B_N_Me	Reminder	Vehicle inspection before a trip	1	Canada	M&SD
Namazu et al. (2019, location B)	B_N_Me	Reminder	Vehicle inspection before a trip	1	Canada	M&SD
Nickerson & Rogers (2010)	B_N_In	Implementation intention	Turnout rate	0	US	BP
Niza et al. (2014)	B_N_Ex	Financial incentives	Chlamydia screening uptake	0	UK	BP
O'Connell & Lang (2018)	B_N_Me	Reminder	Exam score	0.75	US	b
O'Hara & Sparrow (2019)	B_N_Me	Reminder	College reenrollment	0	US	BP
Oppezzo et al. (2019)	B_N_Me	Reminder	Treatment adherence (class attendance)	6	US	M&SD
Otaki et al. (2019)	B_S_At	Color	Household water consumption	5	Japan	2x2
Page & Gehlbach (2017)	B_N_Me	Reminder	College enrollment	4	US	BP
Patel et al. (2017)	B_S_Ef	Active choice	Number of vaccinated patients	7	US	BP
Pugatch & Wilson (2018, framing)	B_N_Pe	Gain framing	Tutoring take-up	0	US	BP
Pugatch & Wilson	B_N_Ex	Financial incentives	Tutoring take-up	0	US	BP

(2018, incentives)						
Pugatch & Wilson (2018, information)	B_N_Pe	Informational messaging	Tutoring take-up	0	US	BP
Raj Chetty et al. (2014 (cash vs. 4 weeks)	B_N_Ex	Financial incentives	Review time in days	2	Worldwide	M&SD
Raj Chetty et al. (2014 (social vs. 6 weeks)	B_N_In	Social norm	Review time in days	2	Worldwide	M&SD
Ranson & Guttentag (2019, study 1)	H_N_In	Social norm	Clean rental unit	0	UK	2x2
Reddy et al. (2017)	B_N_Pe	Informational feedback	Adherence rate	3	US	M&SE
Reiley et al. (2018)	B_N_Ef	Convenience	Percent of donation	0	US	2x2
Robitaille, House, et al. (2020)	B_N_In	Implementation intention	Days taken to file overdue taxes	0	Canada	M&SD
Robitaille, Mazar, et al. (2020, altruism)	B_N_In	Motivational intervention	Organ donor registration	0	Canada	BP
Robitaille, Mazar, et al. (2020, information)	B_N_Pe	Informational messaging	Organ donor registration	0	Canada	BP
Rodriguez-Priego et al. (2016)	B_N_At	Visibility	Amount of personal information disclosed	0	Europe	b
Rohde & Verbeke (2017, 1st quater)	B_S_Ex	Conditional incentives	Number of gym visits	3	Netherlands	b
Rolnick et al. (2020)	B_N_Ef	Convenience	Advance directives completion rate	0	US	2x2

Rommel et al. (2015)	B_N_Pe	Gain framing	Usage of no junk mail sticker	2	Germany	2x2
Samek (2019, gift vs. control)	B_N_Ex	Non-financial incentives	Healthy food choice	0	US	BP
Samek (2019, goal vs. control)	B_N_In	Goal setting	Healthy food choice	0	US	BP
Santana et al. (2019)	B_N_Me	Reminder	Math grade	1	Chile	beta
Schein et al. (2020)	B_N_Me	Reminder	Voter turnout	0	US	2x2
Schippers et al. (2020)	B_N_In	Goal setting	Number of course credits	10	Netherlands	M&SD
Schoar & Tantia (2014)	B_N_Pe	Informational messaging	Amount of savings	0	Pacific Northwest	b
Schwartz et al. (2017, nudge)	B_N_In	Social norm	Colorectal cancer screening uptake	7	US	2x2
Schwartz et al. (2017, quantitative)	B_N_Pe	Informational messaging	Colorectal cancer screening uptake	7	US	2x2
Serper et al. (2020)	B_S_Ex	Conditional incentives	Percent of days with more than 7000 steps	3	US	M&SD
Sharps et al. (2020 (study 1)	B_N_Pe	Graphic	Fruit consumption (grams)	0	UK	F
Shearer et al. (2017)	B_N_Me	Reminder	Weight of food waste	4	UK	M&SD
Shu et al. (2012)	B_N_At	Visibility	Percent of people cheating	0	US	2x2
Somville & Vandewalle (2018)	B_N_Ef	Default	Amount of savings	2.5	India	b
Steinberg et al. (2013)	B_N_Me	Reminder	Weight loss	6	US	M&SD
Stutzer et al. (2011)	B_S_Ef	Active choice	Actual blood donation	0	US	b
Sudarshan (2017)	B_S_In	Social norm	Electricity consumption	4	India	b
Sutter et al. (2020)	B_N_In	Commitment making	Punctual dues payment rate	1	Austria	BP

Tal & Wansink (2015)	B_N_Me	Priming	Amount of purchased fruit and vegetable	0	US	M&SD
Tassiello et al. (2018)	B_S_Ef	Inconvenience	Online ratings of hotel	0.5	UK	b
Tiefenbeck et al. (2018)	B_S_Pe	Informational feedback	Energy use per shower	2	Switzerland;	b
Tonke (2020)	B_N_Pe	Informational messaging	Water consumption	0	Namibia	b
Torres & Carlsson (2018)	B_S_In	Social norm	Water consumption	11	Columbia	MG&SD
Tyers (2018)	B_N_In	Social norm	Purchase of carbon offset	0	UK	2x2
van Bavel et al. (2019)	B_S_Pe	Gain framing	Probability of suffering a cyberattack	0	Europe	M&SD
van Gestel et al. (2020, study 2)	B_N_Ef	Accessibility	Target food choice	0	Netherlands	2x2
van Kleef et al. (2012)	B_N_Pe	Availability	Daily sales of healthy snacks	1	Netherlands	M&SD
van Kleef et al. (2014)	B_N_Pe	Appearance	Whole wheat bread consummated per child	0.25	Netherlands	M&SD
van Teunenbroek & Bekkers (2020)	B_N_In	Social norm	Amount of donation	0	Netherlands	M&SD
Vandenbroele et al. (2019)	B_N_At	Visibility	Sales of meat-free sandwiches	1	Belgium	2x2
Vasiljevic et al. (2019)	B_S_At	Font size	Total calories of sold items	4	UK	b
Wagstaff et al. (2019)	B_N_Me	Reminder	Treatment follow-up	0	US	2x2
Weijers & de Koning (2020, frame)	B_N_Pe	Gain framing	Dispenser use rate	0	Netherlands	2x2
Weijers & de Koning (2020, salience)	B_N_At	Cueing	Dispenser use rate	0	Netherlands	2x2

Wilson et al. (2017, boxed vs. unboxed)	B_S_Pe	Appearance	Uptake of the targeted good	0	US	BP
Wilson et al. (2017, front vs. back)	B_N_Ef	Accessibility	Uptake of the targeted good	0	US	BP
Wright et al. (2017, study1)	B_N_Me	Reminder	Medicaid enrollment	1	US	BP
Wright et al. (2017, study2)	B_N_Me	Reminder	Medicaid enrollment	1.5	US	BP
Wyse et al. (2019)	B_N_At	Visibility	Target food choice	0	Australia	OR
Zarghamee et al. (2017, study 1)	B_N_Ef	Default	Amount of donation	0	US	b
Zhang et al. (2020)	B_N_Me	Reminder	Reported any countable earnings	0	US	b