Preventing hazardous exposure to suspended loads with nudge interventions

Samuël Costa[1] – Wouter Duyck[12] – Nicolas Dirix[1]

[1]Department of Experimental Psychology, Ghent University, Henri Dunantlaan 2, 9000, Ghent, Belgium.

[2] The Accreditation organization of the Netherlands and Flanders (NVAO), Den Haag, Netherlands.

Abstract

This study investigates nudging strategies' effectiveness in enhancing safety practices related to suspended loads in industrial settings. Three field experiments featuring social proof, friction and salience nudges revealed that all interventions effectively increased the distance to suspended loads, promoting safer practices among workers. The social proof experiment found displaying the amount of colleagues following safe pathways increases its usage. The friction experiment found nearby placement of no-touch tools to be more effective than supervisory communication. In the salience experiment, a light projection beneath suspended loads is found to significantly promote keeping distance. These effects persisted over an extended period, signifying long-term safety potential. A layered nudging approach, combining horizontal and vertical strategies, emerged as a key recommendation. Horizontal nudging aims to mitigate risks through multiple simultaneous nudges, while vertical nudging amplifies the impact through a sequence of nudges at different organizational layers. Integrating nudging into current safety practices, guided by cognitive frameworks, offers a holistic approach to safety enhancement. This research contributes practical insights for designing effective workplace safety initiatives, emphasizing the multifaceted nature of safety behavior and the importance of leveraging psychological principles.

Keywords: nudging, industrial safety, safety behavior, layered nudging, bounded rationality

The significance of industrial safety cannot be overstated, as it stands as a pillar of modern society's progress and well-being (Hofmann et al., 2017). Industries, ranging from manufacturing and construction to energy production, play a pivotal role in shaping economies and improving living standards (Stearns, 2020). However, this progress comes with inherent risks that necessitate meticulous attention to safety protocols and ensuring adherence to it. Industrial accidents not only jeopardize the health and lives of workers but can also lead to catastrophic environmental damage (Peterson et al., 2003), economic setbacks (Gavious et al., 2009), and social upheaval (Meshkati, 1998). Through the application of rigorous scientific principles, risk assessment, and the implementation of advanced safety measures, the potential for accidents can be minimized, ensuring the harmonious coexistence of industrial development and human welfare (Beus et al., 2016; Min et al., 2019).

Over the decades, traditional industrial safety approaches have undeniably contributed to improving workplace conditions and reducing accidents. This evolved from technological advancement and better management systems, followed more recently by safety culture (i.e., altering safety norms and values) and behavior-based safety programs (i.e., promoting critical safety behavior through coaching and incentives). Despite their best efforts, industrial safety now seem to have reached a plateau in results obtained with those combined approaches (Hudson, 2007). Research indicates that up to 90% of occupational accidents are human-error related (Kletz, 2001), implying that a better understanding of human errors in interaction with potential hazards (e.g., machinery) can be seen as the last main issue to resolve (Lindhout & Reniers, 2017).

Towards a new safety approach: Bounded rationality and the practice of nudging

The evolving landscape of human behavior and decision-making calls for a fresh perspective to enhance the effectiveness of current safety approaches. Enter 'nudging', a concept rooted in behavioral economics and psychology that holds the potential to foster industrial safety (Thaler & Sunstein, 2008). Unlike traditional approaches that often rely on rules, regulations, and punitive measures, the nudging interventions focus on gently guiding individuals towards safer choices through subtle changes in the physical, social or informational decision context (i.e., choice architecture) (Thaler et al., 2012). Examples are the placement of healthy food at eye-level to increase consumption (increasing visibility and salience[1], Bucher et al. (2016)), the use of a citrus odor to promote hand hygiene (priming[2] subconscious associations, King et al. (2016)) or simple reminder messages to reduce the amount of 'no shows' at dentist check-ups (countering memory lapses, Altmann and Traxler (2014)). Human behavior is inherently influenced by evolutionary drivers and simple heuristics[3] (e.g., 'follow the group'), that are not optimally aligned with modern day complexities and therefore lead to systematic deviations (i.e., cognitive biases) from prescribed goals (e.g., safety protocols) (Kahneman, 2011; Tversky & Kahneman, 1974). Instead of ignoring or denying these biases, nudging starts from their acknowledgment and understanding in order to exploit them in reaching the same goal, by presenting information or altering environments in ways that nudge individuals towards desired behaviors without compromising

[1] Salience is the characteristic of something that stands out from its environment and draws the individual's attention (Taylor & Thompson, 1982).
[2] Priming involves how an initial stimulus can unconsciously affect our response to a subsequent stimulus (Bargh & Chartrand, 2000).
[3] Heuristics, or rules of thumb, are considered an attempt of our brain to deal with an abundance of information in the world relevant for survival. Over the centuries they have become automated and an integrated part of our decision-making process (Tversky & Kahneman, 1974).

their freedom of choice. Humans, for example, have learned implicitly to value social interactions and belonging for a variety of reasons enhancing survival (Aronson, 1994). While a heuristic 'follow the group' might be beneficial in some occasions (e.g., collective climate preserving actions, see Bergquist et al. (2023)), it can also lead to systematic mismatches (cfr., cognitive biases) that steer behavior in a wrong direction (e.g., the spread of fake news, Van Der Linden (2023)). Social norm nudges have shown to capitalize successfully on this heuristic by displaying covert information on what the majority of the group values or does (Bicchieri, 2017). One study showed that providing the social norm message '75% of the people in this room re-use their towel' was able to foster sustainable behavior (Goldstein et al., 2008). For additional nudging examples see Thaler and Sunstein (2008) and Sunstein (2014).

The nudging approach aligns with the modern understanding that human decision-making is boundedly rational, meaning that it is deeply affected by social, cognitive, and emotional factors (Simon, 1955). Kahnemans' (2011) dual-process theory of decision-making captures this adequately by referring to a 'system 1' that is more automatic, subconscious and instinctive, and a 'system 2' that is a more deliberate, effortful and slower. System 1 generates constant implicit impressions of its environment through sensory information and heuristics, and heavily influences the operations of conscious system 2 that only becomes active when situations become more complex[4] (e.g., difficult calculations or deciding which safety protocol to follow). This psychological framework allows us to clarify the underlying mechanisms that drive human behavior and how nudges influence behavior by exploiting system 1 processes (e.g., implicitly linking color to mood,

[4] Captured metaphorically by Kahneman (2011) as 'lazy system 2'

see Tham et al. (2020)) and system 2 limitations (e.g., using reminders to counter the inability to remember everything).

Nudging effectiveness and strategic implementation

Research on nudging underscores its ability to generate significant behavioral changes across diverse domains, including health, finance and sustainability (Bergquist et al., 2023; Raban et al., 2023; Thaler & Benartzi, 2004). For an overview of the average effect sizes and related ongoing discussions, see Mertens et al. (2022), Maier et al. (2022) and Hallsworth (2022). Whether these effects sustain over the long-term has yet to be further investigated (Congiu & Moscati, 2022; Marchiori et al., 2017; Van Rookhuijzen et al., 2021). Nudges often exhibit cost-effectiveness, requiring minimal financial investment compared to traditional approaches. Benartzi et al. (2017) found return on investment ratios per invested dollar by governments to be much higher for nudges (10 – 100) than for informational and educational campaigns (14.68) or economic tax incentives (1.24). While scholars brought ethical considerations to attention (i.e., regarding individual autonomy and transparency), the current consensus supports ethically sound nudges when aligned with mutual beneficial end-goals, such as health and safety (Chowdhury, 2021; Sunstein, 2015).

Nudging taxonomy: a guide for strategic development

Multiple models and frameworks exist to facilitate behavioral change and nudge development (e.g., EAST, COM-B, MINDSPACE; see The Behavioural Insights Team (2014, April 11), (Michie et al., 2011) and Dolan et al. (2010) respectively[5]). While frameworks like EAST aid in adopting a 'behavioral lens' (e.g. make it easy, attractive, social and timely), they remain simple and do not provide sufficient insight in the underlying psychological dynamics of nudge interventions. The framework of Münscher et al. (2016) is more comprehensive and entails a taxonomy of nudging clusters and techniques (also called 'choice architecture techniques') structuring the plethora of nudging interventions that there is today. They define three separate clusters that are based on distinct psychological barriers (see Figure 1).

The first cluster, Decision Information, aims to improve the accessibility, clarity and personal relevance of decision-relevant information. Nudging techniques covered, among others, include social norm messages (e.g., "75% of the people reuse their towel"), framing (e.g., physicians advising a medical method with "a 95% chance of success" more than one with "a 5% chance of death", McGettigan et al. (1999)) or feedback on performance (e.g., "Your energy consumption this month was X" or "Your neighbors consumed less energy on average", Allcott (2011)).

Second, the Decision Structure cluster capitalizes on the context-dependent nature of decision-making by adjusting the arrangement or format of choice options to shape behavior. Related nudging techniques are the use of defaults (e.g., opting-in versus opting-out policy for organ donations, Davidai et al. (2012)), altering the required effort or experienced resistance for

[5] With the acronyms in full being Easy, Attractive, Social and Timely (EAST); Capability, Opportunity, Motivation and Behavior (COM-B); and Messenger, Incentives, Norms, Defaults, Salience, Priming, Affect, Commitments and Ego (MINDSPACE).

choice options (i.e., ‘friction’, Dooley (2019)) (e.g., increasing or decreasing[6] the convenience for healthy food or tobacco and alcohol respectively to alter consumption, Hollands et al. (2017)) or changing the arrangement or composition of choice options (e.g., sustainable food options on top of the menu are chosen more, Langen et al. (2022)).

The final cluster, Decision Assistance, tackles the divide between intention and action by bolstering self-regulation. The objective is to diminish inadvertent behaviors stemming from restricted attention, memory lapses, and a lack of self-discipline. Nudges belonging to this cluster are the use of reminders (e.g., text-based reminder increasing vaccination uptake, Milkman et al. (2021)), salience nudges (e.g., the use of bright colored tread edge highlighters to improve foot placement and prevent falling, Foster et al. (2014)) and pre-commitment (e.g., increased pension-saving by committing to employer-initiated automatic transfers of a fixed paycheck portion into savings, see Thaler and Benartzi (2004)). By utilizing Münscher's taxonomy, nudge designers can strategically align nudges with specific goals and psychological barriers encountered.

[6] While nudging reduces friction of actions that benefit people, the related term ‘sludge’ has been coined for the opposite, interventions increasing friction that impede the appropriate actions (e.g., long text formats to make people agree on the terms without carefully reading it) (Sunstein, 2022b).

Psychological barrier	Intervention category	Intervention technique
Limited access to decision-relevant information	Decision information: increase the availability, comprehensibility, and/or personal relevance of information	Translate information: adapt attributes to facilitate processing of already available information and/or shift decision maker's perspective Make information visible: provide access to relevant information Provide social reference point: provide social normative information to reduce situational ambiguity and behavioral uncertainty
Limited capacity to evaluate and compare choice options	Decision structure: alter the utility of choice options through their arrangement in the decision environment or the format of decision making	Change choice defaults: set no action default or prompt active choice to address behavioral inertia, loss aversion, and/or perceived endorsement Change option-related effort: adjust physical or financial effort to remove friction from desirable choice option Change range or composition of options: adapt categories or grouping of choice options to facilitate evaluation Change option consequences: adapt social consequences or microincentives to address present bias, bias in probability weighting, and/or loss aversion
Limited attention and self-control	Decision assistance: facilitate self-regulation	Provide reminders: increase the attentional salience of desirable behavior to overcome inattention due to information overload Facilitate commitment: encourage self or public commitment to counteract failures of self-control

Figure 1. Taxonomy of choice architecture interventions (after Mertens et al., 2022)

Nudging industrial safety

By integrating nudges into traditional safety strategies, industries can create environments that subtly encourage the adoption of safer behaviors. Although by definition multiple safety interventions qualify as nudges (e.g., use of signs, arrows or colors), to date very few studies exists that examine the potential of nudges as a complementary safety approach (Lindhout & Reniers, 2017). The few explored safety nudges are largely situated in domain of traffic safety. One study found that smiley faces can increase the effectiveness of speed feedback displayed on digital speed signs (cfr., emotional influence system 1) (Gehlert et al., 2012). Despite their potential, industrial safety nudge studies remain scarce, limiting our understanding of their full impact. Some studies do describe industrial safety interventions that can be defined as nudges, such as the use of yellow tread highlighters to promote foot placement on stairs (Foster et al., 2014) or text-reminders for supervisors to promote the frequency of safety talks on a construction site (Rice et al., 2022); but they all lack a compelling framework (cfr., nudge theory and system 1 & 2) to classify all interventions based on the underlying psychological mechanisms.

Multiple lines of defense

When developing industrial safety nudges, it is important to incorporate established insights from the most recent safety models on human error and human factors (Lindhout & Reniers, 2017). Several renowned safety models show the complex interplay of factors leading to an accident. The Human Factors Analysis and Classification System (HFACS) categorizes factors affecting safety into four levels: organizational influences (e.g., suboptimal processes), unsafe supervision, pre-conditions for unsafe acts (e.g., employee knowledge, fatigue or bad weather) and unsafe acts (e.g., intentional violations or unintended error) (Shappell & Wiegmann, 2001; Wiegmann & Shappell, 2001). It offers a structured approach to dissect and mitigate factors contributing to accidents in complex systems (see Figure 2 for a representation of the model). This HFACS model is largely inspired by Reasons' Swiss Cheese Model (Perneger, 2005; Reason, 1990; Reason, 2000), which populated the idea that safety exist out of multiple layers and that accidents only occurs because of flaws in every layer ('through the holes of multiple superimposed cheese slices' hence the metaphor, see Figures 3 and A1 in Appendix for a visual representation). Implementing and improving multiple lines of defense (e.g., better organization, supervision or training) should be able to prevent accidents in different stages, from early contributing organizational factors (e.g., insufficient safety investments) to direct leading factors on the work floor itself (e.g., distraction). Multiple nudge interventions should aim to target multiple lines of defense, simultaneously or sequential, to surpass their smaller individual effects and to leverage the tendency of higher combined effects (or 'additivity') found in multiple studies (Ayal et al., 2021; Brandon et al., 2019).

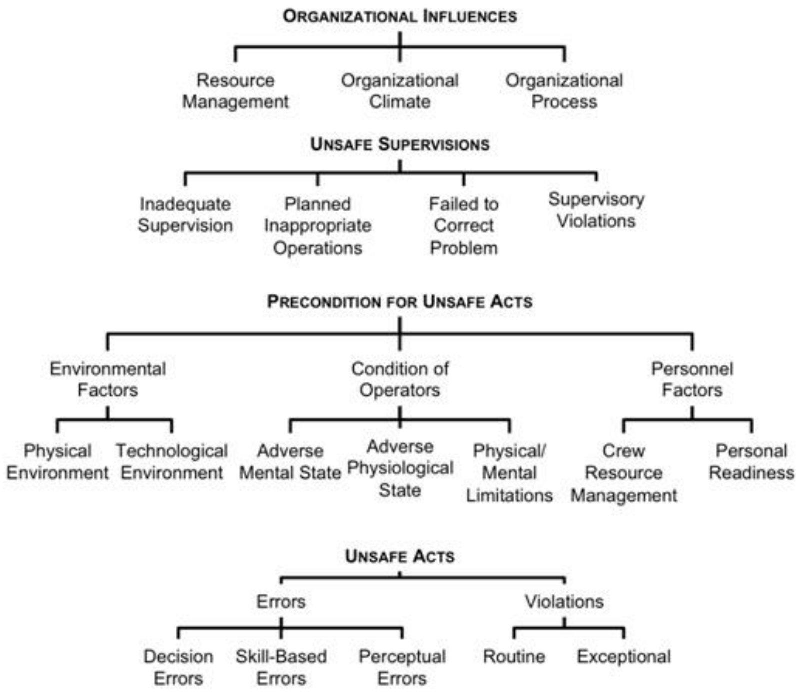

Figure 2. The Human Factors Analysis and Classification System (HFACS) by Shappell and Wiegmann (2001)

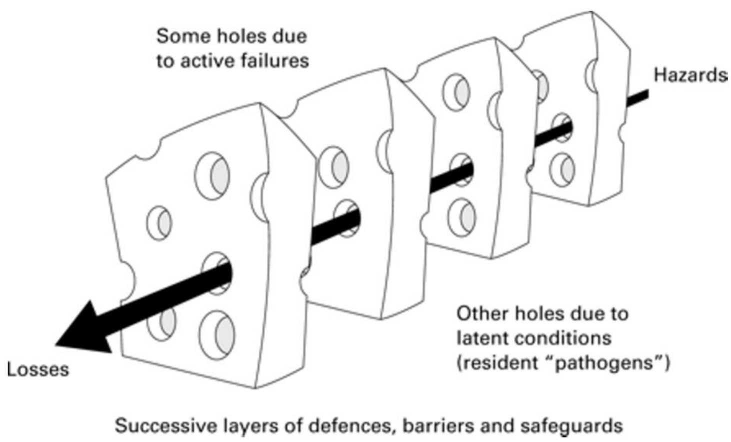

Figure 3. The Swiss Cheese model of Reason (2000), taken from Reason et al. (2001)

Selection of case studies

Typically, working at height, handling heavy loads, contact with moving machines parts, gas hazards and traffic safety account for the largest proportion of accidents (up to 75%) in the process industry (Lindhout & Reniers, 2017). Given that up to 90% of all the occupational accidents are related to human-errors (Kletz, 2001), this is an unexplored promising avenue. While this novel behavioral approach is relevant to most industrial safety domains, and should be investigated in each one of them, it makes sense to start with the domains accounting for the greatest portion of accidents.

In this study, we aim to explore the nudging potential in the domain of handling heavy loads. More specifically, we investigate if nudges can help workers to keep a safe distance to suspended heavy loads (e.g., steel coils or heavy machines parts). Mishandling or insufficient precautions during load movement can lead to life-threatening injuries, equipment damage, and production disruptions (de la Colina & Cervera, 2016; Häkkinen, 1982). Moreover, the complex and dynamic nature of such tasks demands precise adherence to safety protocols (OSHA, 2010b). Given the various layers that play a role in causing accidents, the aim is to investigate if multiple nudges on multiple layers prove successful in preventing unsafe behaviors. For handling suspended loads, we focus on three areas that account for a great deal of incidents, being a) the use of safe pathways, b) the use of no-touch tools (i.e. tools allowing a safe distance) and c) the visibility and awareness of suspended loads. To this end, for each area, we will analyze the behavioral factors that are at play to develop adequate nudges accordingly.

By investigating how to develop safety nudges and assessing their effectiveness in one domain (i.e. handling suspended loads), we aim to provide insights in the usefulness of nudging as novel safety tool for the process industry. One that, if successful, can and should be explored in other industrial safety domains as well.

Current Study

Three experiments are carried out to evaluate the effectiveness of nudges in reducing behavioral flaws in multiple lines of defense related to hazardous suspended load exposure (cfr., HFCAS and the Swiss Cheese model); focusing mainly on the same layer of 'unsafe acts' (Figure 2) and therefore using a more horizontal approach[7]. For all experiments, we selected the most fitting design, accounting for a multitude of constraints in real-life settings (e.g., sparse eligible locations, confounding influences and budget and time limitations). The eligible locations, with suspended load activities, were chosen based on various criteria, including the possibility to observe unnoticed and sufficient sample sizes; leaving only one or two options. The composition of the teams is very consistent (e.g., predominantly men with an average age around 43 and 13-19 years of seniority), ensuring all locations had a similar sample. For privacy reasons instructed by the ethical committee, the data for the experiments was collected on a group level, rather than an individual level; limiting analysis across participant characteristics.

A set of observations and interviews, with workers, supervisors and safety experts, was performed for each experiment one month in advance to determine relevant psychological barriers and environmental factors. A core element here lies in identifying which causes underlie unsafe behaviors and if they are a result of human errors (e.g., forgetting), a rather more intentional violation (e.g., not complying to safety measures deemed 'redundant') or a combination of both (cfr., 'Unsafe acts' in the HFACS model). By observing and performing the interviews, we consistently aim to get a good understanding of psychological factors and barriers,

[7] As opposed to a vertical approach that would use nudges to target flawed decision-making on multiple different layers of the hierarchy (e.g., nudging unsafe acts, unsafe supervision and organizational decision-making). While this vertical approach is highly relevant, it falls out of the scope of the current study (because of feasibility).

forming the fundament of adequate nudge development. For each experiment, the framework of Münscher et al. (2016) was used to guide nudge development by linking the underlying behavioral factors to the appropriate nudge clusters (i.e., Decision Information, Decision Structure and Decision Assistance); providing a consistent methodology.

Experiment 1 - Following safe pathways

The first experiment aims to nudge people in following the designated safe paths in the factories, guarding them from falling loads, entrapment and other potential hazards (e.g., contact with moving machine parts). Several behavioral elements play a role in adhering to this safety protocol, such as the visibility of the safe paths (e.g., green color), their logical and time-efficient placement in the factory and the social influence of colleagues complying with tracks or not. This experiment focuses on social norms that play a pivotal role in influencing safety behavior, because people often adhere to what their peers do, trying to fit in with the group (cfr., herd behavior and conformity, see Banerjee (1992) and Asch (1956) respectively). A distinction can be made between descriptive norms (i.e., what people actually do, also called 'social proof') and injunctive social norms (i.e., what people value or deem appropriate). Research has shown that descriptive norms plays a bigger role in influencing an individual's own decision, whereas injunctive norms play a bigger role in influencing recommendations to others (Zou & Savani, 2019). Moreover, norm nudging appears to be more effective when it entails norms of one's local setting and circumstances (i.e., provincial norms, see Goldstein et al. (2008). The nudge tested in this experiment includes a descriptive norm (or social proof) nudge displaying data (i.e., a digital sign) of the amount of colleagues using the safety pathways to create a positive peer influence (i.e., increasing the access to decision relevant social information, cfr., cluster Decision Information).

We believe this nudge will lead to a small significant increase of people using the safety pathways, in line with the norm nudging literature (Hypothesis 1) (Bicchieri, 2017).

Experiment 2 - No-touch tools

The second experiment investigates a holistic approach to increase the use of no-touch tools, which are devices designed to enable hands-free operation of equipment or processes (e.g., a stick or a rope). The aim of these tools is to reduce the risk of injury by minimizing direct contact with potentially hazardous machinery or materials. This experiment aims to address flaws in multiple lines of defense with both nudges and more standard (safety) interventions combined, which to date is generally investigated separately (Beshears & Kosowsky, 2020). A first intervention involves the mere communication of supervisors to the workers that no-touch tools are of paramount importance for safety and should be used consistently where possible[8]. By using their supervisor as messenger (i.e., increasing the relevance, cfr., Decision Information), at least a small effect of this message is expected (Hypothesis 2); in line with the literature of messenger effects (Hafner et al., 2019). Secondly, previous studies have shown that altering the placement of a product might increase their usage (e.g., increased consumption of healthy food, see Bucher et al. (2016)). By placing the no-touch tools closer to the workstations (i.e., reducing friction and effort, cfr., Decision Structure), that are currently often centralized in the workplace of the industrial plant, we expect a small significant effect on its usage (Hypothesis 3). Given that the decision structure cluster is typically considered the most effective of all three (Mertens et al., 2022), a slightly bigger effect is expected for the placement than for the communication

[8] To date there is no strict obligations for using no-touch tools, safeguarding worker autonomy and exploring non-intrusive interventions before installing obligations and control mechanisms (that require consistent supervision).

(Hypothesis 4). Another important element, which came up during the interviews, was that some of these tools are considered impractical to use (e.g., a thick rope of 8m to guide a load). Based on input of the workers on potential better equipment during a brainstorm, some new tools are introduced at the work floor (i.e., a more typical safety intervention of introducing new tools, together with allowing participation) and expected to have a small to medium effect on their usage (Hypothesis 5). By working on multiple aspects of no-touch tool compliance (cfr., multiple lines of defense), we aim to maximize the effect towards behavior change.

Experiment 3 – Visibility and awareness of suspended loads

The third experiment addresses a different aspect contributing to hazardous exposure to suspended loads, namely the compromised awareness of nearby employees and suspended load visibility. Heavy loads are often transported over larger distances, from a couple to hundreds of meters, inside or nearby the factories. While often risk zones are indicated with restricted access, in many occasions people have to pass or work nearby suspended moving loads. The nudge in this experiment aims to promote awareness in order to keep distance to the suspended load (cfr., 'triangle principle' handled by the industrial plant, distance should be proportionate to the height, see also VESI (2016), OSHA (2010a) and OSHA (2016)) by projecting a red and white light circle beneath the load. This light projection aims to increase the salience of the suspended load by directing attention towards it (i.e., supporting attention with environmental cues, cfr., Decision Assistance). By adding a red color, it is also expected to signal and prime potential danger, leading to increased risk perception and subsequent safety behavior (Luximon et al., 1998; Pravossoudovitch et al., 2014). Both directing attention and priming safety behaviors target system 1 processes directly. In addition, the light circle provides guidance on how far people exactly should stand when working nearby (cfr., triangle principle), which on sight is not always easy to determine (or at least prone to errors). We believe that projecting light circles will draw attention to the load's presence and potential hazards, having a small significant effect on workers keeping more distance (Hypothesis 6). As during the pre-observations, one month in advance, we noticed that people might act differently in group (e.g., older colleague entering the circle and younger colleagues following suit), we expect that the effect on compliance might be different for individuals in group (Hypothesis 7).

Experiment 1

The industrial plant involved in this study processes iron ores into finished products through a variety of large departments, including raw materials, cokes factory, steel factory, hot-rolling mill, cold-rolling mill, galvanization lines, general services (i.e., maintenance) and refining departments (i.e., making detailed end-products). The first experiment takes place in the Cold-Rolling Mill (CRM) where many heavy steel coils (e.g., 30 tons) are transported with cranes along the factory.

Method

Participants

The participants include the employees of the CRM, with the exception of some external employees of other departments or contractors passing-by (a maximum of 5%). At the CRM there are four shifts[9] guaranteeing continuous staffing for constant production. Every shift employs around 120 workers, with approximately 480 to 500 workers on a daily basis (mainly male blue-collar workers). The internal employees of the CRM (N= 597) have a mean age of 43.35 years (SD

[9] Three rotating shifts (morning 6:00-14:00, evening 14:00-22:00 and night 22:00-6:00) and a day shift (8:00-16:00)

= 11.59) and mean seniority of 19.88 years (SD = 12.61). A total of 11 360 observations is collected using camera footage (preventing potential Hawthorne effects). Before starting this study, approval is obtained from the labor unions representing all employees, informing them about the content of the study, interventions and privacy implications. Summaries of the results are freely accessible for the employees on their intranet website. Ethical clearance for this study is provided by the safety department of the industrial plant.

Design and procedure

A within-subjects design is used including a baseline measurement of 2 weeks (control), followed by a test measurement (active social proof nudge) in the subsequent third, fourth and fifth week. The social proof (or descriptive norm) nudge involves a digital sign that counts and displays the amount of workers that used the safe pathway that day and that month. Note that we deliberately decided to only display the amount of people that used the safe road, and not the ones that do not to prevent adverse social norm effects (in case the majority would not comply). A permanent message on top of the sign says “Together safe on the green path” in Dutch (see Figure 4)[10]. A camera is used to observe the amount of passers-by using the safe path, when passing in the direction facing the sign (i.e., the main direction of passersby).

Data analysis

Binary logistic regression analyses are carried to analyze the binary dependent variable (using the safe path = 1 or not =0) among control and test conditions. The odds ratio (small 1.5, medium 2.5 and large 4; see Chinn (2000), Hasselblad and Hedges (1995) and Sánchez-Meca et al.

[10] While the green color of the path in Figure 4 for a large part decayed, ‘green path’ remains a consistently used and known term to the employees of the industrial plant (i.e., a synonym for ‘safe pathway’)

(2003)) and Cohens D (0.2 = small, 0.5= medium, 0.8 = large) are calculated as effect size measures. The statistical analyses are conducted using IBM SPSS Statistics version 27.

Figure 4. A digital sign displaying the amount of passers-by on the safe pathway

Results

The results of the binary logistic regression can be found at Table 1**.** They show that, consistent with our prediction, the social proof nudge has a positive significant effect on the usage of the safe path. In contrast to our hypothesis, the effect of the social proof nudge is not small but large for the first week with an OR of 3.80 ($p < .01$, 95% CI: 3.30 - 4.38), even higher in the second week with an OR of 4.87 ($p < .01$, 95% CI: 4.20 - 5.64) and the highest in the third week with an OR of 5.36 ($p < .01$, 95% CI: 4.57 - 6.29). The Cohens' D is equally provided in Table 2 as an alternative effect size. Figure 5 represents the amount of passersby using the safe path in percentage per condition.

Table 1. The results of the binary logistic regression (Experiment 1)

VARIABLES	Usage safe path		
	Exp (B)	95% C.I.	*d*
Social proof (week 1)	3.80*** (18.56)	3.30 - 4.38	*0.74*
Social proof (week 2)	4.87*** (21.11)	4.20 - 5.64	*0.87*
Social proof (week 3)	5.36*** (20.48)	4.57 - 6.29	*0.93*
Observations	11 360		

Note. z-statistics in parentheses; *** p < .01, ** p < .05, * p < .1; reference level for interventions 'Baseline (control)'.

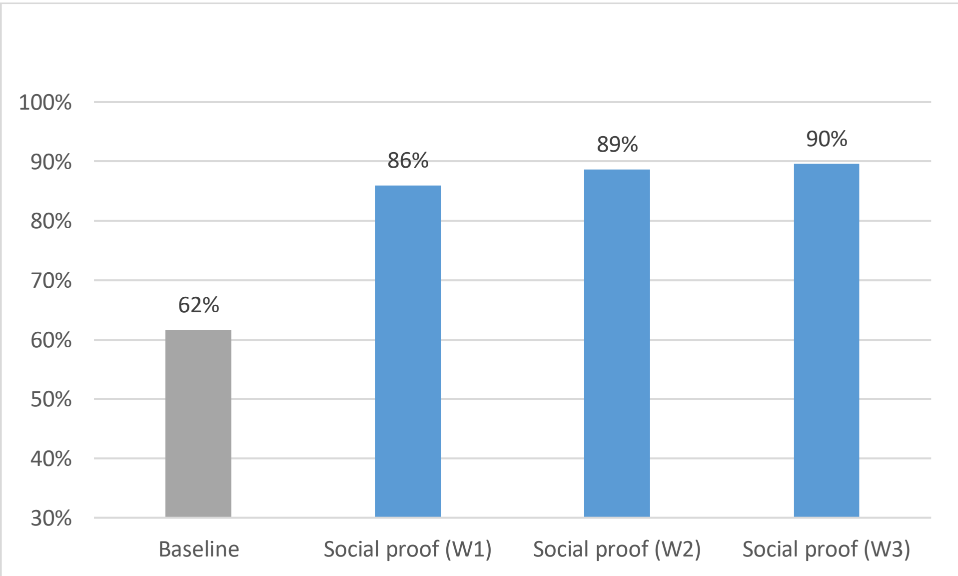

Figure 5. The amount of people using the safe pathway (in %)

Experiment 2

The second experiment takes place at the central workshop of the General Services (GS) department. This department takes care of the maintenance of machine parts, including heavy ones that need to be lifted on workstations and transported inside the warehouse. Therefore, no-touch tools are advised to use.

Method

Participants

The participant sample exists solely out of internal workers from the central workshop of the GS department. A total of 52 participants work there, all working during a day shift. The workers are all male with a mean age of 43.99 years (SD = 11.85) and mean seniority of 19.72 years (SD = 11.38). A total of 500 observations is collected by two trained independent observers from a higher located office space, invisible to the workers, with an overview of all workstations of the warehouse. The procedures for obtaining ethical approval and providing feedback to the employees were identical to Experiment 1.

Design

A within-subjects design is used including a baseline measurement (control) and four subsequent test conditions (communication, placement of no-touch tools, new tools implementation and long-term follow-up). Every condition lasts one week, with 5 weeks in total (with the long-term follow-up taking place 6 months later). The communication condition includes an email sent by their supervisor (i.e., line manager) displaying a photo of the no-touch tools (see Figure 6) and the following message “Handling suspended heavy loads contains a high safety risk, therefore we strongly advice and expect you to use the no-touch tools where possible” in Dutch.

A brief verbal repetition of this message was also provided at the beginning of the week. The placement condition includes moving the current no-touch tools from a central point in the warehouse to every workstation individually (reducing a 2 minute walk to seconds) (see Figure A2 in Appendix for the indication on the work shop floor plan). For the last test condition, the old no-touch tools (see Figure 6 and 7) are replaced with new ones, based on input received during the preparatory interviews and observations performed one month in advance. The need for better, more stable and practical tools was mentioned and met by the new set of tools (see Figures 8 and 9). The long impractical rope to guide suspended loads is replaced by a dog leash that rolls up the excess rope automatically, a creative solution cleared by the safety department[11]. These new tools are again placed nearby the workstations. A long-term follow up is carried out 6 months later (i.e., one week of observations), with the new tools and their altered placement nearby the workstations remaining active. Binary logistic regression analyses are carried to analyze the binary dependent variable (using the no-touch tools = 1 or not = 0, on every occasion where a no-touch could be used) among control and test conditions. The odds ratio and Cohens D are calculated as effect size measures.

[11] Such a rope or leash allows employees to guide a suspended load over a longer distance and at times more flexible use than sticks, but is of course restricted to pulling actions

Figure 6. An example of a suspended load

Figure 7. The old no-touch tools

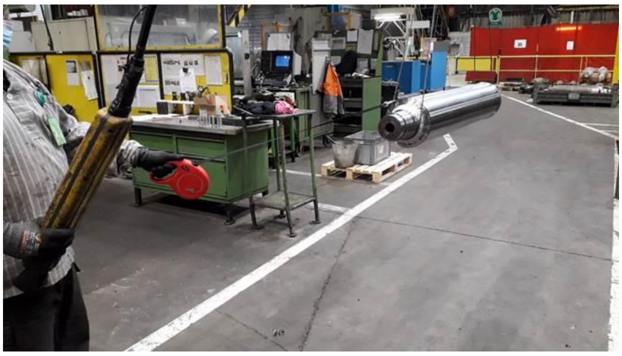

Figure 8. The usage of the new dog leash

Figure 9. The new no-touch tools

Results

The results of the binary regression analysis in Table 2 show that all interventions, except for the communication intervention (i.e., the line manager highlighting the importance of no-touch tools), had a positive significant effect on the usage of the no-touch tools. Inconsistent with our prediction, the effect of the communication is insignificant with an OR of 1.65 (p > .05, 95% CI: 0.52

- 5.24), while at least a small positive effect was expected. A large significant positive effect is found from the placement nudge on the use of no-touch tools with an OR of 10.23 ($p < .01$, 95% CI: 0.52 - 5.24). This effect increases significantly when in the subsequent condition new tools are combined with better placement, involving an OR of 99.75 ($p < .01$, 95% CI: 35.04 - 283.97), and holds largely over a period of 6 months with an OR of 76 ($p < .01$, 95% CI: 27.29 - 211.63). See Figure 10 for a representation in percentages of the amount of people using the no-touch tools among all conditions.

Table 2. The results of the binary logistic regression (Experiment 2)

VARIABLES	Usage no-touch tools		
	Exp (B)	95% C.I.	*d*
Communication	1.65 (0.85)	0.52 - 5.24	*0.28*
Placement (friction)	10.23*** (4.61)	3.81 - 27.50	*1.28*
Placement + New tools	99.75*** (8.62)	35.04 - 283.97	*2.54*
Follow-up (6m)	76*** (8.28)	27.29 - 211.63	*2.39*
Observations	500		

Note. z-statistics in parentheses; *** p < .01, ** p < .05, * p < .1; reference level for interventions 'Baseline (control)'.

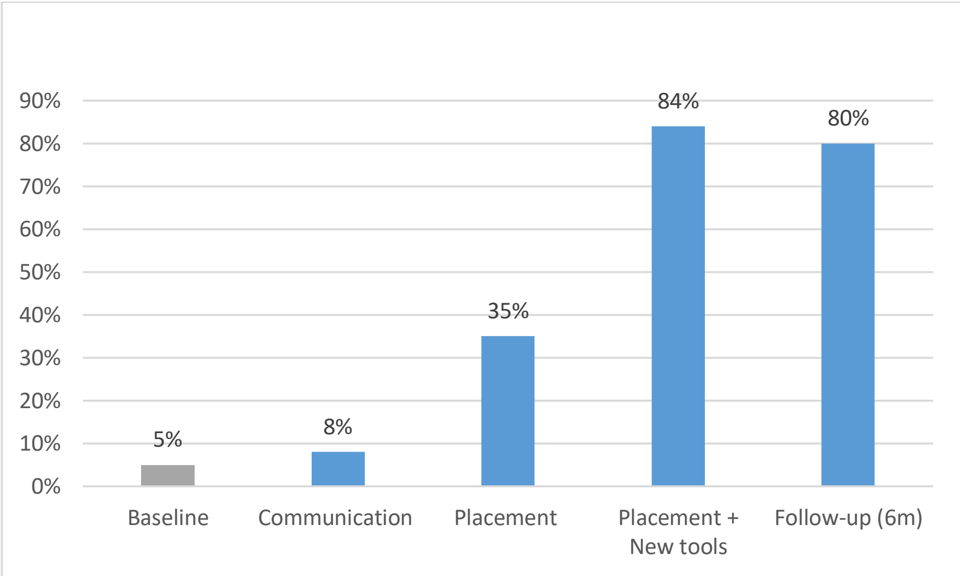

Figure 10. The amount of people using the no-touch tools (in %)

Experiment 3

The third experiment takes places at one of the refining departments, Steel Decoration (SD), where decorative steel parts are produced and steel coils are packed for transport. These heavy steel coils are transported by cranes and lifted on the appropriate spot for packing. This can lead to dangerous exposure to the suspended loads when the safe distance is not respected.

Method

Participants

The sample exist out of 36 external workers from the SD department (i.e., packing and transporting coils outsourced to external firm). The workers are all male with a mean age of 38.62 years (SD = 10.12) and mean seniority of 13.05 years (SD = 12.79). A total of 516 observations of workers transporting heavy loads is collected using camera footage[12]. The procedures for obtaining ethical approval and providing feedback to the employees were identical to Experiments 1 and 2.

Design

The third experiment has a within-subjects design with a baseline measurement (i.e., control) followed by a test condition (i.e., light projection beneath load) and a follow-up one month later (i.e., light projection remaining active). All three conditions last one week. A light projector is added to the crane and is activated once the crane picks up a load (i.e., by pressing on two push button on the hook using gravity). A red and white circle is projected beneath the load which adapts to the height by increasing the circles diameter (cfr., triangle principle; see Figure 11). In this experiment, we observed if workers and passers-by keep distance to the load (i.e., not entering the projected circle) when it is moving to and hanging above the workstation. Binary logistic

[12] Exceeding the necessary sample size of 361 to find a small effect prescribed by the power analysis (using G*Power)

regression analyses are carried to analyze the binary dependent variable (standing outside the red circle = 1 or inside = 0; with a 0 given to an individual entering the circle minimum one time per transfer, with two transfers per steel coil that come and go) among the control and test condition. The odds ratio and Cohens D are calculated as effect size measures.

Figure 11. A red-white light projection of a circle beneath the suspended load

Results

Table 3 displays the results of the binary regression analysis. These results indicate, consistent with our predictions, that the light projection (i.e., salience nudge) has a significant positive effect on keeping distance to the suspended load (i.e., outside the red circle) when compared to the baseline. In contrast to our hypothesis, the effect is large instead of small with an OR of 7.16 ($p < .01$, 95% CI: 2.35 - 21.83). This effect remains large and significant over a period of one month, but seems to know a small decline with an OR of 4.14 (p < .01, 95% CI: 0.08 – 1.63). Based on the observations using camera footage, it appears that workers who are not complying often try to perform an action (e.g., scanning the coil) before the coil hits the ground or to correct an action when the coils is already lifted of the ground (e.g., adjusting the packaging of the coil). Because our pre-observations indicated social influence from colleagues could play a role, we looked at the impact of being in group (i.e., at least with two persons), but found no significant effect on keeping distance to the suspended load with an OR of 0.37 (p > .05, 95% CI: 0.08 - 1.63). Figure 12 represent the percentage of people outside the red circle when near a suspended load for all conditions.

Table 3. The results of the binary logistic regression (Experiment 3)

VARIABLES	Distance to suspended load		
	Exp (B)	95% C.I.	*d*
Light projection	7.16*** (3.46)	2.35 - 21.83	*1.09*
Light projection (1m)	4.14*** (3.05)	1.66 - 10.31	*0.78*
Group	0.37 (-1.32)	0.08 - 1.63	*-0.56*
Observations	516		

Note. z-statistics in parentheses; *** p < .01, ** p < .05, * p < .1; reference level for interventions ‘Baseline (control)’.

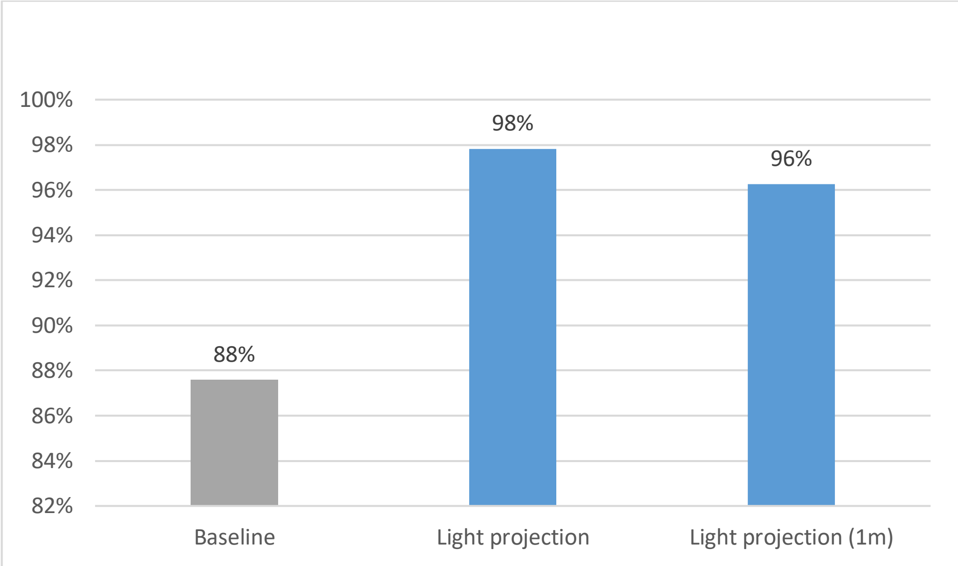

Figure 12. Amount of people standing outside the projected red-white circle (in %)

Discussion

This study contributes to the applied understanding of nudging strategies within industrial contexts and offers insights into the potential of specific interventions to influence safety practices concerning suspended loads. Ultimately, the results will aid in designing more effective workplace safety initiatives and contribute to the ongoing discourse on enhancing occupational health and safety.

Nudging distance to suspended loads

One of the central findings of this study is the effectiveness of various nudging interventions in increasing the distance to suspended loads. These interventions encompassed a range of strategies, each with its unique approach and rationale.

Following safe pathways

The deployment of a digital sign showing the frequency of colleagues using the safe path is rooted in the concept of social proof (or descriptive social norms) (Cialdini, 2013). This powerful psychological principle suggests that individuals are more likely to emulate behavior they perceive as the norm (Bicchieri, 2017); capitalizing on the evolutionary need for social inclusion and relatedness (cfr., system 1) (Aronson, 1994; Deci & Ryan, 2000). In this context, the digital sign displays those (covert) norms visually (cfr., Decision-Information). The results indicate that a social proof nudge can lead to a large significant increase of employees using the safe pathways by displaying descriptive norms (i.e., what are colleagues actually doing); which is larger than the typical small to medium effect we can expect from the literature (Bergquist et al., 2023; Bicchieri, 2017). A potential moderator can be the (private) company context, as opposed to nudges more commonly investigated in the public domain (Kubera, 2023), and forms a promising avenue for further research.

Note that displaying only the frequency of desired behavior, in contrast to both desired and undesired (i.e., not following the safe paths), can be strategic when the undesired behavior has a chance to be more prevalent (i.e., preventing reversed social norms effects) (Cialdini et al., 2006). While in our study many of the participants were not aware of the identity of other people in the sample (i.e., workers from other shifts or subsections), in less populated settings, the visible compliance with the safety rules ("What do the workers in front of me?") can receive a greater weight (cfr., local or provincial norms, see Goldstein et al. (2008)). This can moderate the effect of a sign displaying the amount of people complying (e.g., "I know how it is done in practice, you cannot fool me").

In addition, it appears that, as the displayed frequency increases, workers are increasingly (be it slightly) motivated to follow suit. This implies that social proof interventions become more effective when representing a larger (proportion of a) peer group, which is consistent with what we would expect based on the literature (Cialdini et al., 2006). By harnessing the power of social norms, one could facilitate the development of a new safety culture that is more adept to modern safety requirements (Naji et al., 2022).

The use of no-touch tools

All of the interventions appeared to increase the use of the no-touch tools significantly, apart from the communication of the supervisor highlighting its importance. At least some effect of the message was expected given the associated messenger effect (Hafner et al., 2019). The effect of the message might have been bigger if it was conveyed by more closely related supervisors (e.g., foremen or team leader) instead of the line manager ('n+1' or direct supervisors have shown to exert a bigger influence, see OECD (2020)).

The placement of no-touch tools is a practical example of reducing friction, which basically comes down to subtly altering the required effort (or the perception of it, Dooley (2019)). By making safe choices more convenient and altering their utility through rearrangement (cfr., Decision-Structure), this intervention eliminates some of the obstacles that may have previously deterred workers from adhering to safety protocols (cfr., notifying and removing 'sludges', see Sunstein (2022b) and Thaler (2021)). Although the increased visibility likely had some moderating effect (Wansink et al., 2006), it is considered minimal given the absent difference in the baseline for workstation that had the tools in sight.

Moreover, the combination of the placement with more standard safety interventions, such as better tools developed through bottom-up brainstorming, had a remarkable effect, reaching an impressive 84% usage. This underscores the potential synergy between nudge-based approaches and more technical, worker-driven safety initiatives (Lindhout & Reniers, 2017). Further testing should refine what degree of the effect originates from the better tools themselves, in relation to the bottom-up approach and convenient and visible placement.

Visibility and awareness of suspended loads

The use of a salient light projection (cfr., Decision Assistance), providing real-time feedback on the exact distance relative to the height of the suspended load (cfr., Decision Information), proved to be an incredibly effective nudging intervention. The projected red and white circle beneath the suspended load successfully nudges employees to keep distance, almost reaching full compliance (98%). This aligns with previous research indicating that making the desired action more salient can have a positive effect (cfr., Decision-Assistance), but the effect is considerably higher than expected (Ischen et al., 2022).

One potential reason is the obvious personal and direct benefit of safe actions in a high-risk situation that can moderate the salience effect (although this varies among individuals with different personality traits, Beus et al. (2015)). Another likely reason, is the cumulative effect of combined elements, including salient aspects, but also increased visibility of unsafe actions (cfr., social norms) and the adaptive feedback element of the light projection. In fact, our findings suggest that providing feedback, involving the adaptive diameter of the circle relative to the height, can assist in deciding how far 'far enough' is exactly (cfr., Decision-Information) (Cappa et al., 2020). Yet, further research should confirm this by investigating a projected circle with and without adapting to the height to define the added value of the feedback component. In addition, previous studies have shown how a red color can prime danger (Pravossoudovitch et al., 2014), yet further experimentation will have to indicate if the red color is determining for the effect of the light projection or if other colors (e.g., blue) work as well.

By increasing the salience of the suspended load, it makes the workers acutely aware of their proximity to potential dangers, requiring little cognitive effort and thus drawing mainly on system 1 processing. This has the advantage that in cognitive demanding situation, common for industrial settings (i.e., fatigue, difficult task or time pressure; related to 'cognitive load', see Sweller (1988) and Aldekhyl et al. (2018)), workers are still being nudged to safety, while system 2 depending processes (e.g., actively monitoring every risk) might run out of fuel, fail and fall back on system 1 ('willpower as a limited resource', cfr., 'ego depletion' and the exhausted system 2, see Kahneman (2011)). By achieving nearly full compliance, this nudge intervention demonstrates the power of real-time, context-sensitive feedback (Buckley, 2020) and attention-drawing environmental cues (Wilson et al., 2016) in influencing safety behavior.

Furthermore, the longevity of the effects observed in this study is noteworthy. All interventions across the three experiments retained their effectiveness over an extended period (i.e., varying from one to six months, and counting), indicating that the impact of nudges and nudge combinations with standard safety interventions extend beyond short-term compliance (a delicate matter in the nudging literature that remains poorly understood, see Hallsworth (2023), Marchiori et al. (2017) and Thaler (2021)). This has significant implications for workplace safety, as sustained adherence to safety practices is paramount in preventing accidents and injuries (Krause et al., 1999; Spigener et al., 2022).

A layered nudging approach

The reasoning advocated by Reason's Swiss Cheese model (Perneger, 2005; Reason, 2000) and HFCAS (Shappell & Wiegmann, 2001) to reinforce multiple lines of defense can be extended to nudge applications. The findings of this study indicate that nudges can promote multiple facets (e.g., following safe paths, using no-touch tools and keeping distance) that contribute to hazardous exposure to suspended loads and call for the adoption of an integrated nudging approach that consistently targets multiple lines of defenses in industrial safety contexts. We propose a new concept of 'layered nudging' as a new promising way forward, discriminating between horizontal and vertical layered nudging strategies.

Horizontally layered nudging, as demonstrated in this study, involves multiple small nudges that collectively mitigate risks on the same implementation level or layer. Using the example of the hierarchical HFCAS model (Figure 2), this can involve multiple nudges targeting unsafe acts of workers on the work floor (layer 'unsafe acts'), or multiple nudges that aim to promote the frequency and quality of supervision (layer 'unsafe supervision'). For instance, workers may initially be nudged to follow safe paths through the use of digital signs (utilizing social proof). If compliance remains suboptimal, they might receive additional nudges, such as a salient cue to maintain a safe distance through light projections beneath moving suspended loads. By implementing multiple small nudges simultaneously (or rapid succession), the eventual likelihood of accidents can be significantly reduced through the cumulative effect of nudges (i.e., targeting different behavioral barriers) that has been found in previous studies (Ayal et al., 2021; Brandon et al., 2019; Wilson et al., 2016).

On the other hand, vertically layered nudging targets agents in different layers of an organization (i.e., managers, supervisors, workers, etc.), not only targeting the last person to perform an unsafe action (typically 'the common man', while more voices rise to equally 'nudge the nudger', see Dudley and Xie (2022) and House et al. (2022)). Vertical layered nudging thus targets multiple layers of defense sequentially, in contrast to horizontally layered nudging that implement multiple nudge interventions on the same line of defense (e.g., unsafe acts of workers as a result of interaction with the direct work floor environment). Nudging supervisors to conduct more safety talks (Rice et al., 2022), for example, can increase safety awareness among those workers (Hoonakker et al., 2005) and keep safety top of mind (cfr., WYSIATI[13] or the availability heuristic, a mental shortcut relying on immediate or recent examples of information that come to mind to form thoughts and guide subsequent action, see Kahneman (2011)). These talks can amplify the motivation for using safe paths, increasing the susceptibility to our nudge visualizing social norms using a digital sign (i.e., people who have stronger preferences for something are more easily nudges, and vice versa, see de Ridder et al. (2022)). They might also enhance responsiveness to a salient light projection beneath suspended loads (here serving as a reminder), as research on the availability heuristic shows that recent accidents (and presumably also related talks about risk) largely influence future risk estimations and subsequent safety behavior (Slovic, 2000).

Both layered nudging approaches hold the potential to tackle popular nudge criticism of generally small effect sizes (DellaVigna & Linos, 2022) and to elevate current safety management by countering flawed decision-making on multiple levels contributing to occupational (fatal) accidents (Shappell & Wiegmann, 2001; Vierendeels et al., 2018).

Integrating nudging in current safety practice

The integration of nudging, particularly through a layered approach, into current safety practices represents a holistic and multifaceted approach to enhancing safety behavior in industrial settings. This approach recognizes that safety is influenced by a complex interplay of factors, including culture, technology, and management (Reason, 2000; Shappell & Wiegmann, 2001; Vierendeels et al., 2018).

[13] WYSIATI ('What You See Is All There Is')

The practice of nudging and associated techniques (Thaler & Sunstein, 2008), as well as Kahneman's (2011) metaphorical two systems of decision-making (i.e., System 1 and 2), provides a valuable framework for understanding safety behavior at a deeper level. Nudging can effectively target both systems, making safety decisions more automatic (System 1) while also promoting and assisting timely conscious deliberation when needed (System 2). By aligning nudging strategies with these cognitive processes, organizations can create a more comprehensive and effective approach to safety (Lindhout & Reniers, 2017).

Moreover, the clusters of Münscher et al. (2016) (i.e., Decision-Information, Decision-Structure and Decision-Assistance) offer a taxonomy for categorizing existing and future nudging interventions (or 'choice architecture interventions') in the realm of industrial safety. These clusters help identify and strategize nudge development based on relevant psychological barriers and allow for meaningful comparison of which nudging techniques worked in what contextual conditions for which target audiences (cfr., a 'heterogeneity approach', indicated as the way forward by nudging experts, see Bryan et al. (2021)). In essence, Münscher's framework provides a roadmap for tailoring nudges to specific organizational contexts and psychological profiles, thereby optimizing their impact.

The potential integration of nudging into various domains of industrial safety highlights its versatility in enhancing safety outcomes. In chemical plants, for example, nudging can be (and is already) applied through visual cues, such as color-coded indicators on control panels, to guide workers toward safer, more automatic decisions when managing hazardous materials (Lindhout & Reniers, 2017). For more complex scenarios, such as emergency shutdowns, tools like simplified checklists and (social) feedback loops can help workers to complete each step and follow critical safety procedures. In manufacturing environments, nudging can reduce accidents by making safety features, like emergency stop buttons, more intuitive and easily accessible, allowing for quick responses under stress. A recent study on nudging safety in the steel industry showed that a danger icon on the jacket (i.e., a skull on a red triangle, with 'CO detector here!' below) had a small positive effect on gas detector compliance, and that hand-shaped stickers can improve people holding rails when using the stairs (Costa et al., 2024). The wide range of nudging interventions tested in the domain of traffic safety are relevant for industrial sites as well and the traffic of motorized vehicles on it. One example is the use of smiley faces that can enhance the efficacy of speed feedback displayed on digital signs (Gehlert et al., 2012), driven by social (dis)approval and emotional influence. These examples demonstrate how nudging can be tailored to address both routine tasks and more complex decision-making in various domains (for a broader overview of safety nudges relevant to industrial safety, see Lindhout & Reniers (2017)).

While (industrial) safety domains do vary in the specific tasks being performed, procedures that need to be followed, working conditions, required level of expertise and knowledge and so forth; the same principles of safety nudge development in these domains remain the same. It comes down to a) identifying and analyzing the problem situation (from a technical, organizational and human perspective), b) assessing human factors at play (ranging between less and more conscious elements, originating in various layers of the safety process, cfr. HFACS), and c) designing appropriate nudging strategies (matching human factors with relevant choice architecture interventions, cfr. clusters of Münscher et al. (2016)) as part of a holistic safety approach. By aligning nudging strategies with the specific cognitive needs of workers in different environments, organizations can create more effective and resilient safety practices.

Limitations and further research

While this study has provided valuable insights into the potential of nudging in industrial safety, it is essential to acknowledge its limitations and avenues for future research.

Firstly, future (lab) studies could address the inherent constraints that are present in field studies, which have impact on the feasibility of certain designs (Cartwright, 2007; Samek, 2019). For example, incorporation of additional between subject control groups, in addition to the within-subjects baseline measure, could further validate the observed effects and enhance the robustness of the findings. . Additionally, certain test conditions consisted of the simultaneous manipulation of multiple elements or interventions (e.g., colored light projection providing feedback; placement and new tools). To refine the implementation of these interventions, future research should aim to discriminate the most active components within them by dissecting and testing variations of the most successful applications. Also, a lower baseline can play a role, for example 5% in the current study for the no-touch tools (being impractical or outdated), making re-evaluation of the interventions in contexts with a higher initial compliance rate (e.g., between 20 – 50%) important. Beshears and Kosowsky (2020) indicate that both field and laboratory research should be used as complimentary methods to advance empirical nudging literature by meeting each other shortcomings (i.e., external versus internal validity). Specifically for nudging safe handling of suspended loads, additional testing of which variations (e.g. manipulating colors, salience levels, feedback references, degrees of reduced friction) of the successful interventions in this study and which combinations (i.e. both combining nudges, as combinations with more traditional safety measures and participatory approaches) work best, are promising avenues to increase safety compliance.

Secondly, this study focused more on a horizontal layered approach, targeting multiple barriers on the same hierarchical 'layer' (i.e., unsafe acts of workers, cfr., HFACS), in different but related contexts relevant to hazardous exposure to suspended loads. Future research should evaluate the effect of the horizontal layered approach at intersections where all nudges are active simultaneously, or in rapid succession, to evaluate its combined effect on safety behavior (e.g., in the same department). The vertical approach remains to be explored, as most nudge studies target the behavior of the final person in line directly (e.g., worker performing unsafe acts) (Dudley & Xie, 2022; House et al., 2022). While this is equally a corner stone of nudging (i.e., 'influencing the problematic behavior directly'), it also entails a narrow-minded vision on how 'problematic behavior', such as unsafe behavior, occurs and can be prevented (Shappell & Wiegmann, 2001; Vierendeels et al., 2018). By targeting suboptimal decision-making on all layers of the organization hierarchy (i.e., multiple lines of defense), leading directly or indirectly to an undesired outcome, the nudging approach incorporates 'system thinking' which is deemed invaluable for lasting behavior change and further advancement of the behavioral science field (Hallsworth, 2023). This also includes further investigation of how nudges interact with standard safety interventions (e.g., resource allocation, campaigns, coaching and incentives), highlighted as a point of attention in the recent synthesis of nudging literature of Beshears and Kosowsky (2020). Related, the framework of Münscher et al. (2016) was selected to optimize (safety) nudge development in the current study, but additional models for behavioral change (e.g. COM-B and the behavior change wheel, see Michie et al. (2011)) and safety culture approaches leveraging System 1 and 2 principles (OECD,

2020) could be considered in designing safety interventions. So, while nudge development forms one aspect, and is the core focus of this study, these models and approaches allow a wider perspective on how safety management can benefit from a bounded rationality approach and their applications should be explored in more depth as well, in tandem or together with the related nudging strategies.

Lastly, the scalability of the interventions to different locations and contexts remains an important area for investigation (DellaVigna & Linos, 2022; Hallsworth, 2022). Context is key, but its effect on nudging remains enigmatic (Bryan et al., 2021; Marchiori et al., 2017). More research is needed that defines (industrial) contextual moderators and mediators of nudge effectiveness (Sunstein, 2022a), other than the presence of strong preferences ('for' or 'against') that correlate with 'nudgeability' (de Ridder et al., 2022). Consistently, post-surveys of participants to examine their internal thoughts and perceptions regarding the interventions would provide valuable qualitative data. Understanding how workers perceive and react to nudges can inform the design of more tailored and effective interventions (Mills, 2022), and might clarify the moderating role of reflection (cfr., 'nudge plus', see Banerjee and John (2021)). Closely related to scalability is the widespread adoption of online nudging strategies (both online and mobile text-based nudges) in the field of behavioral science because of its wide reach and potential impact with minimal costs (Milkman et al., 2021). Very few studies have explored the potential of online nudging strategies for industrial safety; one example is the study of Rice et al. (2022) which found text-messages containing a reminder as well as suggested topics to perform a safety talk, increased the level of safety talks on a construction site by 19%. Note that these mobile nudges can more easily be personalized and iterated as well, further increasing their chances of success (Mills, 2022). The potential of (cost-)effective safety nudges communicated via mobile channels is significant and needs further exploration, especially in times with fast evolving artificially intelligent applications (Mills et al., 2023), while still remaining aware of potential distractions (e.g. use of phone) and cognitive overload (e.g. too many messages) that might come along.

Conclusion

This study underscores the potential of nudging strategies to enhance safety practices in industrial settings. Various nudging interventions, including social proof, friction and salience, effectively increased distances to suspended loads, ensuring improved workplace safety. Crucially, these effects persisted largely over time, solidifying nudging's role as a sustainable safety measure. The call for a layered nudging approach, comprising horizontal and vertical strategies, emphasizes the multifaceted nature of safety behavior. By addressing various dimensions of safety simultaneously, this approach minimizes risk by countering flaws in multiples lines of defense. Integrating nudging into current safety practices, guided by cognitive frameworks and psychological principles, offers a holistic safety improvement strategy. Future research should explore how personal characteristics impact the effectiveness of nudges, as well as which variations and combinations of nudges, alongside traditional safety measures, are most effective. Additionally, it should focus on standardizing processes for identifying human errors and developing layered nudging strategies across different safety domains. Still, further investigation of the scalability, contextual moderators, and persistence of nudge effects over time is needed, together with the assessment of the wider potential of the concept of bounded rationality in the field of industrial safety beyond nudging.

Appendix

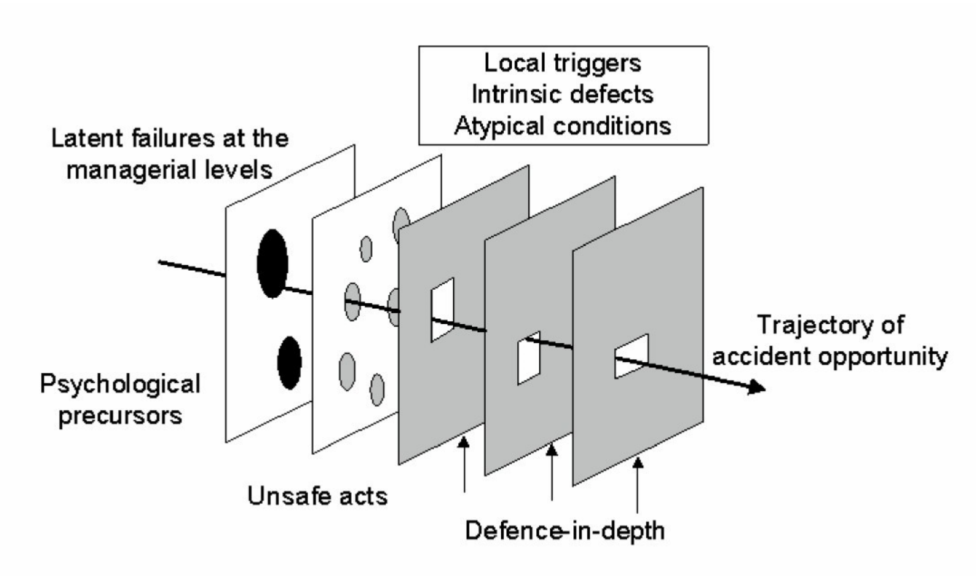

Figure A1. Early stages of the Swiss Cheese model by Reason (1990)

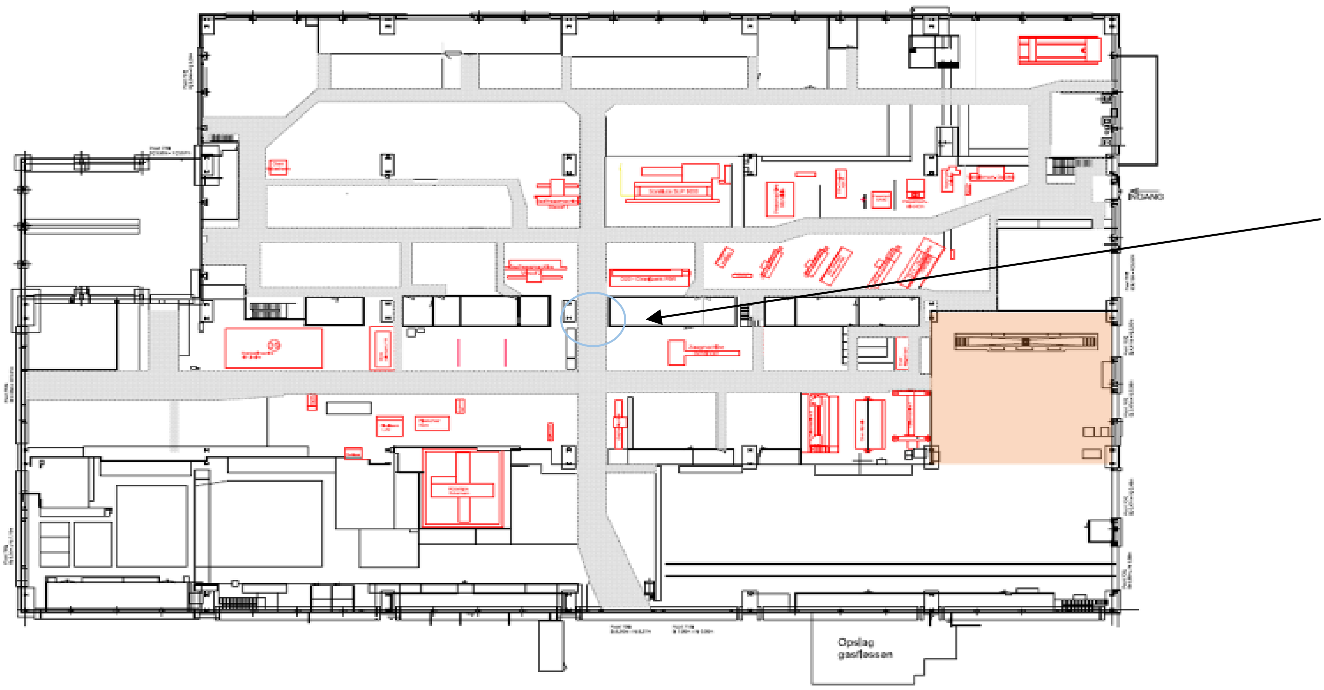

Figure A2. The floor plan of the central workshop of the General Services (GS), indicating the original placement of the old no-touch tools (arrow) and the workstations (in red).

References

Aldekhyl, S., Cavalcanti, R. B., & Naismith, L. M. (2018). Cognitive load predicts point-of-care ultrasound simulator performance. *Perspect Med Educ*, *7*(1), 23-32. https://doi.org/10.1007/s40037-017-0392-7

Allcott, H. (2011). Social norms and energy conservation. *Journal of Public Economics*, *95*(9-10), 1082-1095. https://doi.org/10.1016/j.jpubeco.2011.03.003

Altmann, S., & Traxler, C. (2014). Nudges at the dentist. *European Economic Review*, *72*, 19-38. https://doi.org/https://doi.org/10.1016/j.euroecorev.2014.07.007

Aronson, E. (1994). *The social animal* (7th ed. ed.). W H Freeman.

Asch, S. E. (1956). Studies of independence and conformity: I. A minority of one against a unanimous majority. *Psychological Monographs*, *70*(9), 1-70. https://doi.org/doi:10.1037/h0093718

Ayal, S., Celse, J., & Hochman, G. (2021). Crafting messages to fight dishonesty: A field investigation of the effects of social norms and watching eye cues on fare evasion. *Organizational Behavior and Human Decision Processes*, *166*, 9-19. https://doi.org/https://doi.org/10.1016/j.obhdp.2019.10.003

Banerjee, A. V. (1992). A Simple-Model of Herd Behavior. *Quarterly Journal of Economics*, *107*(3), 797-817. https://doi.org/Doi 10.2307/2118364

Banerjee, S., & John, P. (2021). Nudge plus: incorporating reflection into behavioral public policy. *Behavioural Public Policy*, 1-16. https://doi.org/10.1017/bpp.2021.6

Bargh, J. A., & Chartrand, T. L. (2000). The mind in the middle: A practical guide to priming and automaticity research. In *Handbook of research methods in social and personality psychology.* (pp. 253-285). Cambridge University Press.

Benartzi, S., Beshears, J., Milkman, K. L., Sunstein, C. R., Thaler, R. H., Shankar, M., Tucker-Ray, W., Congdon, W. J., & Galing, S. (2017). Should Governments Invest More in Nudging? *Psychological Science*, *28*(8), 1041-1055. https://doi.org/10.1177/0956797617702501

Bergquist, M., Thiel, M., Goldberg, M. H., & van der Linden, S. (2023). Field interventions for climate change mitigation behaviors: A second-order meta-analysis. *Proceedings of the National Academy of Sciences*, *120*(13), e2214851120. https://doi.org/doi:10.1073/pnas.2214851120

Beshears, J., & Kosowsky, H. (2020). Nudging: Progress to date and future directions. *Organizational Behavior and Human Decision Processes*, *161*, 3-19. https://doi.org/10.1016/j.obhdp.2020.09.001

Beus, J., Dhanani, L., & McCord, M. (2015). A Meta-Analysis of Personality and Workplace Safety: Addressing Unanswered Questions. *Journal of Applied Psychology*, *100*, 481-498. https://doi.org/10.1037/a0037916

Beus, J. M., McCord, M. A., & Zohar, D. (2016). Workplace safety:A review and research synthesis. *Organizational Psychology Review*, *6*(4), 352-381. https://doi.org/10.1177/2041386615626243

Bicchieri, C. (2017). *Norms in the Wild: How to Diagnose, Measure, and Change Social Norms*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780190622046.001.0001

Brandon, A., List, J. A., Metcalfe, R. D., Price, M. K., & Rundhammer, F. (2019). Testing for crowd out in social nudges: Evidence from a natural field experiment in the market for electricity. *Proc Natl Acad Sci U S A*, *116*(12), 5293-5298. https://doi.org/10.1073/pnas.1802874115

Bryan, C., Tipton, E., & Yeager, D. (2021). Behavioural science is unlikely to change the world without a heterogeneity revolution. *Nature Human Behaviour*. https://doi.org/10.1038/s41562-021-01143-3

Bucher, T., Collins, C., Rollo, M. E., McCaffrey, T. A., De Vlieger, N., Van der Bend, D., Truby, H., & Perez-Cueto, F. J. A. (2016). Nudging consumers towards healthier choices: a systematic review of positional influences on food choice. *British Journal of Nutrition*, *115*(12), 2252-2263. https://doi.org/10.1017/S0007114516001653

Buckley, P. (2020). Prices, information and nudges for residential electricity conservation: A meta-analysis. *Ecological Economics*, *172*, 106635. https://doi.org/https://doi.org/10.1016/j.ecolecon.2020.106635

Cappa, F., Rosso, F., Giustiniano, L., & Porfiri, M. (2020). Nudging and citizen science: The effectiveness of feedback in energy-demand management. *Journal of Environmental Management*, *269*, 110759. https://doi.org/https://doi.org/10.1016/j.jenvman.2020.110759

Cartwright, N. (2007). Are RCTs the Gold Standard? *BioSocieties*, *2*(1), 11-20. https://doi.org/10.1017/S1745855207005029

Chen, H., Cohen, P., & Chen, S. (2010). How Big is a Big Odds Ratio? Interpreting the Magnitudes of Odds Ratios in Epidemiological Studies. *Communications in Statistics - Simulation and Computation*, *39*(4), 860-864. https://doi.org/10.1080/03610911003650383

Chinn, S. (2000). A simple method for converting an odds ratio to effect size for use in meta-analysis. *Statistics in Medicine*, *19*(22), 3127-3131. https://doi.org/https://doi.org/10.1002/1097-0258(20001130)19:22<3127::AID-SIM784>3.0.CO;2-M

Chowdhury, R. M. M. I. (2021). The ethics of nudging: Using moral foundations theory to understand consumers' approval of nudges. *Journal of Consumer Affairs*. https://doi.org/10.1111/joca.12431

Cialdini, R. B. (2013). *Influence: Science and Practice* (5th ed.). Pearson.

Cialdini, R. B., Demaine, L. J., Sagarin, B. J., Barrett, D. W., Rhoads, K., & Winter, P. L. (2006). Managing social norms for persuasive impact. *Social Influence*, *1*(1), 3-15. https://doi.org/10.1080/15534510500181459

Congiu, L., & Moscati, I. (2022). A review of nudges: Definitions, justifications, effectiveness. *Journal of Economic Surveys*, *36*(1), 188-213. https://doi.org/https://doi.org/10.1111/joes.12453

Costa, S., Duyck, W., Van Wouwe, E., & Dirix, N. (2024). Nudging safety behavior in the steel industry: Evidence from two field studies. *Safety Science*, *173*, 106444. https://doi.org/https://doi.org/10.1016/j.ssci.2024.106444

Davidai, S., Gilovich, T., & Ross, L. D. (2012). The meaning of default options for potential organ donors. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(38), 15201-15205. https://doi.org/10.1073/pnas.1211695109

de la Colina, M. F., & Cervera, M. R. (2016). Handling Heavier Loads in Construction. *Procedia Engineering*, *161*, 1127-1134. https://doi.org/https://doi.org/10.1016/j.proeng.2016.08.524

de Ridder, D., Kroese, F., & van Gestel, L. (2022). Nudgeability: Mapping Conditions of Susceptibility to Nudge Influence. *Perspectives on Psychological Science*, *17*(2), 346-359. https://doi.org/10.1177/1745691621995183

Deci, E. L., & Ryan, R. M. (2000). The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior. *Psychological Inquiry*, *11*(4), 227-268. https://doi.org/10.1207/S15327965PLI1104_01

DellaVigna, S., & Linos, E. (2022). RCTs to Scale: Comprehensive Evidence From Two Nudge Units. *Econometrica*, *90*(1), 81-116. https://doi.org/10.3982/Ecta18709

Dolan, P., Hallsworth, M., Halpern, D., King, D., & Vlaev, I. (2010). MINDSPACE: influencing behaviour for public policy.

Dooley, R. (2019). *Friction: The Untapped Force That Can Be Your Most Powerful Advantage*. McGraw-Hill Education.

Dudley, S. E., & Xie, Z. (2022). Nudging the nudger: Toward a choice architecture for regulators. *Regulation & Governance*, *16*(1), 261-273. https://doi.org/https://doi.org/10.1111/rego.12329

Foster, R. J., Hotchkiss, J., Buckley, J. G., & Elliott, D. B. (2014). Safety on stairs: Influence of a tread edge highlighter and its position. *Experimental Gerontology*, *55*, 152-158. https://doi.org/https://doi.org/10.1016/j.exger.2014.04.009

Gavious, A., Mizrahi, S., Shani, Y., & Minchuk, Y. (2009). The costs of industrial accidents for the organization: Developing methods and tools for evaluation and cost–benefit analysis of investment in safety. *Journal of Loss Prevention in the Process Industries*, *22*(4), 434-438. https://doi.org/https://doi.org/10.1016/j.jlp.2009.02.008

Gehlert, T., Schulze, C., & Schlag, B. (2012). Evaluation of different types of dynamic speed display signs. *Transportation Research Part F: Traffic Psychology and Behaviour*, *15*(6), 667-675. https://doi.org/https://doi.org/10.1016/j.trf.2012.07.004

Goldstein, N. J., Cialdini, R. B., & Griskevicius, V. (2008). A room with a viewpoint: Using social norms to motivate environmental conservation in hotels. *Journal of Consumer Research*, *35*(3), 472-482. https://doi.org/10.1086/586910

Hafner, R., Elmes, D., & Read, D. (2019). Exploring the Role of Messenger Effects and Feedback Frames in Promoting Uptake of Energy-Efficient Technologies. *Current Psychology*, *38*(6), 1601-1612. https://doi.org/10.1007/s12144-017-9717-2

Häkkinen, K. (1982). The progress of technology and safety in materials handling. *Journal of Occupational Accidents*, *4*(2), 157-163. https://doi.org/https://doi.org/10.1016/0376-6349(82)90019-0

Hallsworth, M. (2022). Making Sense of the “Do Nudges Work?” Debate. https://behavioralscientist.org/making-sense-of-the-do-nudges-work-debate/

Hallsworth, M. (2023). A manifesto for applying behavioural science. *Nature Human Behaviour*, *7*(3), 310-322. https://doi.org/10.1038/s41562-023-01555-3

Hasselblad, V., & Hedges, L. V. (1995). Meta-analysis of screening and diagnostic tests. *Psychol Bull*, *117*(1), 167-178. https://doi.org/10.1037/0033-2909.117.1.167

Hofmann, D. A., Burke, M. J., & Zohar, D. (2017). 100 years of occupational safety research: From basic protections and work analysis to a multilevel view of workplace safety and risk. *Journal of Applied Psychology*, *102*(3), 375-388. https://doi.org/10.1037/apl0000114

Hollands, G. J., Bignardi, G., Johnston, M., Kelly, M. P., Ogilvie, D., Petticrew, M., Prestwich, A., Shemilt, I., Sutton, S., & Marteau, T. M. (2017). The TIPPME intervention typology for changing environments to change behaviour. *Nature Human Behaviour*, *1*(8), 0140. https://doi.org/10.1038/s41562-017-0140

Hoonakker, P., Loushine, T., Carayon, P., Kallman, J., Kapp, A., & Smith, M. J. (2005). The effect of safety initiatives on safety performance: A longitudinal study. *Applied Ergonomics*, *36*(4), 461-469. https://doi.org/https://doi.org/10.1016/j.apergo.2004.07.006

House, J., Lacetera, N., Macis, M., & Mazar, N. (2022). Nudging the nudger: A field experiment on the effect of performance feedback to service agents on increasing organ donor registrations. *National Bureau of Economic Research.* https://doi.org/https://doi.org/10.3386/w30547

Hudson, P. (2007). Implementing a safety culture in a major multi-national. *Safety Science*, *45*(6), 697-722. https://doi.org/https://doi.org/10.1016/j.ssci.2007.04.005

Ischen, C., Meijers, M. H. C., Vandeberg, L., & Smit, E. G. (2022). Seen as Green? Assessing the Salience and Greenness of Environmentally Friendly Packaging Cues. *Journal of Food Products Marketing*, *28*(1), 31-48. https://doi.org/10.1080/10454446.2022.2038757

Kahneman, D. (2011). *Thinking, Fast and Slow*. Farrar, Straus and Giroux. https://books.google.be/books?id=ZuKTvERuPG8C

King, D., Vlaev, I., Everett-Thomas, R., Fitzpatrick, M., Darzi, A., & Birnbach, D. J. (2016). "Priming" Hand Hygiene Compliance in Clinical Environments. *Health Psychology*, *35*(1), 96-101. https://doi.org/10.1037/hea0000239

Kletz, T. (2001). *An Engineers view of Human Error.* Institute of Chemical Engineers.

Krause, T. R., Seymour, K. J., & Sloat, K. C. M. (1999). Long-term evaluation of a behavior-based method for improving safety performance: a meta-analysis of 73 interrupted time-series replications. *Safety Science*, *32*(1), 1-18. https://doi.org/https://doi.org/10.1016/S0925-7535(99)00007-7

Kubera, P. (2023). Nudging in the workplace: Moving beyond the traditional management toolbox *Scientific Papers Of Silesian University Of Technology*, *172*(Organization and Management Series). https://managementpapers.polsl.pl/wp-content/uploads/2023/06/172-Kubera.pdf

Langen, N., Ohlhausen, P., Steinmeier, F., Friedrich, S., Engelmann, T., Speck, M., Damerau, K., Bienge, K., Rohn, H., & Teitscheid, P. (2022). Nudges for more sustainable food choices in the out-of-home catering sector applied in real-world labs. *Resources, Conservation and Recycling*, *180*, 106167. https://doi.org/https://doi.org/10.1016/j.resconrec.2022.106167

Lindhout, P., & Reniers, G. (2017). What about nudges in the process industry? Exploring a new safety management tool. *Journal of Loss Prevention in the Process Industries*, *50*, 243-256. https://doi.org/https://doi.org/10.1016/j.jlp.2017.10.006

Luximon, A., Chung, L., & Goonetilleke, R. (1998). Safety Signal Words and Color Codes: The Perception of Implied Hazard by Chinese People.

Maier, M., Bartoš, F., Stanley, T. D., Shanks, D. R., Harris, A. J. L., & Wagenmakers, E.-J. (2022). No evidence for nudging after adjusting for publication bias. *Proceedings of the National Academy of Sciences*, *119*(31), e2200300119. https://doi.org/doi:10.1073/pnas.2200300119

Marchiori, D. R., Adriaanse, M. A., & De Ridder, D. T. D. (2017). Unresolved questions in nudging research: Putting the psychology back in nudging. *Social and Personality Psychology Compass*, *11*, No Pagination Specified-No Pagination Specified. https://doi.org/10.1111/spc3.12297

McGettigan, P., Sly, K., O'Connell, D., Hill, S., & Henry, D. (1999). The effects of information framing on the practices of physicians. *J Gen Intern Med*, *14*(10), 633-642. https://doi.org/10.1046/j.1525-1497.1999.09038.x

Mertens, S., Herberz, M., Hahnel, U. J. J., & Brosch, T. (2022). The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains. *Proceedings of the National Academy of Sciences of the United States of America*, *119*(1). https://doi.org/ARTN e210734611810.1073/pnas.2107346118

Meshkati, N. (1998). Lessons of Chernobyl and Beyond: Creation of the Safety Culture in Nuclear Power Plants. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *42*(10), 745-749. https://doi.org/10.1177/154193129804201019

Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science*, *6*(1), 42. https://doi.org/10.1186/1748-5908-6-42

Milkman, K. L., Patel, M. S., Gandhi, L., Graci, H. N., Gromet, D. M., Ho, H., Kay, J. S., Lee, T. W., Akinola, M., Beshears, J., Bogard, J. E., Buttenheim, A., Chabris, C. F., Chapman, G. B., Choi, J. J., Dai, H. C., Fox, C. R., Goren, A., Hilchey, M. D., . . . Duckworth, A. L. (2021). A megastudy of text-based nudges encouraging patients to get vaccinated at an upcoming doctor's appointment. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(20). https://doi.org/ARTN e210116511810.1073/pnas.2101165118

Mills, S. (2022). Personalized nudging. *Behavioural Public Policy*, *6*(1), 150-159. https://doi.org/10.1017/bpp.2020.7

Mills, S., Costa, S., & Sunstein, C. R. (2023). AI, Behavioural Science, and Consumer Welfare. Journal of Consumer Policy. https://doi.org/10.1007/s10603-023-09547-6

Min, J., Kim, Y., Lee, S., Jang, T.-W., Kim, I., & Song, J. (2019). The Fourth Industrial Revolution and Its Impact on Occupational Health and Safety, Worker's Compensation and Labor Conditions. *Safety and Health at Work*, *10*(4), 400-408. https://doi.org/https://doi.org/10.1016/j.shaw.2019.09.005

Münscher, R., Vetter, M., & Scheuerle, T. (2016). A Review and Taxonomy of Choice Architecture Techniques. *Journal of Behavioral Decision Making*, *29*(5), 511-524. https://doi.org/https://doi.org/10.1002/bdm.1897

Naji, G. M. A., Isha, A. S. N., Alazzani, A., Saleem, M. S., & Alzoraiki, M. (2022). Assessing the Mediating Role of Safety Communication Between Safety Culture and Employees Safety Performance. *Frontiers in Public Health*, *10*, 840281. https://doi.org/10.3389/fpubh.2022.840281

OECD (2020). *Behavioural Insights and Organisations: Fostering Safety Culture*. https://doi.org/doi:https://doi.org/10.1787/e6ef217d-en

OSHA (2010a). *Hoisting and rigging*. Retrieved August 31 from https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.753

OSHA (2010b). *Keeping clear of the load*. Retrieved August 31 from https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.1425

OSHA (2016). *Duty to have fall protection and falling object protection.* Retrieved August 31 from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.28

Perneger, T. V. (2005). The Swiss cheese model of safety incidents: are there holes in the metaphor? *BMC Health Serv Res*, *5*, 71. https://doi.org/10.1186/1472-6963-5-71

Peterson, C. H., Rice, S. D., Short, J. W., Esler, D., Bodkin, J. L., Ballachey, B. E., & Irons, D. B. (2003). Long-Term Ecosystem Response to the Exxon Valdez Oil Spill. *Science*, *302*(5653), 2082-2086. https://doi.org/doi:10.1126/science.1084282

Pravossoudovitch, K., Cury, F., Young, S. G., & Elliot, A. J. (2014). Is red the colour of danger? Testing an implicit red–danger association. *Ergonomics*, *57*(4), 503-510. https://doi.org/10.1080/00140139.2014.889220

Raban, M. Z., Gates, P. J., Gamboa, S., Gonzalez, G., & Westbrook, J. I. (2023). Effectiveness of non-interruptive nudge interventions in electronic health records to improve the delivery of care in hospitals: a systematic review. *Journal of the American Medical Informatics Association*. https://doi.org/10.1093/jamia/ocad083

Reason, J. (1990). *Human Error*. Cambridge University Press.

Reason, J. (2000). Human error: models and management. *Bmj*, *320*(7237), 768-770. https://doi.org/10.1136/bmj.320.7237.768

Reason, J., Carthey, J., & de Leval, M. R. (2001). Diagnosing “vulnerable system syndrome”: an essential prerequisite to effective risk management. *Quality in Health Care*, *10*(suppl 2), 21-25. https://doi.org/10.1136/qhc.0100021..

Rice, S. P. M., Rimby, J., Hurtado, D. A., Gilbert - Jones, I., & Olson, R. (2022). Does sending Safety Toolbox Talks by text message to Residential Construction Supervisors increase Safety Meeting Compliance? *Occupational Health Science*, *6*(3), 313-332. https://doi.org/10.1007/s41542-022-00118-8

Samek, A. (2019). Chapter 6: Advantages and disadvantages of field experiments. In *Handbook of Research Methods and Applications in Experimental Economics* (pp. 104–120, 448). Edward Elgar Publishing. https://doi.org/https://doi.org/10.4337/9781788110563.00014

Sánchez-Meca, J., Marín-Martínez, F., & Chacón-Moscoso, S. (2003). Effect-size indices for dichotomized outcomes in meta-analysis. *Psychol Methods*, *8*(4), 448-467. https://doi.org/10.1037/1082-989x.8.4.448

Shappell, S., & Wiegmann, D. (2001). Applying Reason: The human factorsanalysis and classification system (HFACS). *Human Factors and AerospaceSafety*, *1*(1), 59-86.

Simon, H. A. (1955). A Behavioral Model of Rational Choice. *The Quarterly Journal of Economics*, *69*(1), 99-118. https://doi.org/10.2307/1884852

Slovic, P. (2000). *The perception of risk*. Earthscan Publications.

Spigener, J., Lyon, G., & McSween, T. (2022). Behavior-based safety 2022: today's evidence. *Journal of Organizational Behavior Management*. https://doi.org/10.1080/01608061.2022.2048943

Stearns, P. N. (2020). *The Industrial Revolution in World History* (5th Edition ed.). Routledge. https://doi.org/https://doi.org/10.4324/9781003050186

Sunstein, C. (2015). Nudges and Choice Architecture: Ethical Considerations. *Yale journal on regulation (forthcoming)*.

Sunstein, C. R. (2014). Nudging: A Very Short Guide. *Journal of Consumer Policy*, *37*(4), 583-588. https://doi.org/10.1007/s10603-014-9273-1

Sunstein, C. R. (2022a). The distributional effects of nudges. *Nature Human Behaviour*, *6*(1), 9-10. https://doi.org/10.1038/s41562-021-01236-z

Sunstein, C. R. (2022b). Sludge Audits. *Behavioural Public Policy*, *6*(4), 654-673. https://doi.org/PII S2398063X1900032010.1017/bpp.2019.32

Sunstein, C. R. (2022c). *Sludge: What Stops Us from Getting Things Done and What to Do about It*. The MIT Press.

Sweller, J. (1988). Cognitive Load During Problem Solving: Effects on Learning. *Cognitive Science*, *12*(2), 257-285. https://doi.org/https://doi.org/10.1207/s15516709cog1202_4

Taylor, S. E., & Thompson, S. C. (1982). Stalking the Elusive Vividness Effect. *Psychological Review*, *89*(2), 155-181. https://doi.org/Doi 10.1037/0033-295x.89.2.155

Thaler, R. (2021). What's next for nudging and choice architecture? *Organizational Behavior and Human Decision Processes*, *163*, 4-5. https://doi.org/https://doi.org/10.1016/j.obhdp.2020.04.003

Thaler, R., & Benartzi, S. (2004). Save More Tomorrow™: Using Behavioral Economics to Increase Employee Saving. *Journal of Political Economy*, *112*(S1), S164-S187. https://doi.org/10.1086/380085

Thaler, R., & Sunstein, C. (2008). *Nudge: Improving decisions about health, wealth, and happiness*. Yale University Press.

Thaler, R., Sunstein, C., & Balz, J. (2012). Choice Architecture. In. https://doi.org/10.13140/2.1.4195.2321

Tham, D. S. Y., Sowden, P. T., Grandison, A., Franklin, A., Lee, A. K. W., Ng, M., Park, J., Pang, W., & Zhao, J. (2020). A systematic investigation of conceptual color associations. *J Exp Psychol Gen*, *149*(7), 1311-1332. https://doi.org/10.1037/xge0000703

The Behavioural Insights Team (2014, April 11). *East: Four simple ways to apply behavioural insights.* Retrieved August 31 from https://www.bi.team/publications/east-four-simple-ways-to-apply-behavioural-insights/

Tversky, A., & Kahneman, D. (1974). Judgment under Uncertainty - Heuristics and Biases. *Science*, *185*(4157), 1124-1131. https://doi.org/DOI 10.1126/science.185.4157.1124

Van Der Linden, S. (2023). *Foolproof: Why Misinformation Infects Our Minds and How to Build Immunity*. W.W. Norton & Company.

Van Rookhuijzen, M., De Vet, E., & Adriaanse, M. A. (2021). The Effects of Nudges: One-Shot Only? Exploring the Temporal Spillover Effects of a Default Nudge [Original Research]. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.683262

VESI. (2016). *Guidance Note for Drop ZoneManagement within the Victorian Electricity Supply Industry*. Retrieved August 31 from http://www.vesi.com.au/files/WorkPractices/Guidance_Note_for_Drop_Zone_Management_within_the_VESI_-_February_2016.pdf

Vierendeels, G., Reniers, G., van Nunen, K., & Ponnet, K. (2018). An integrative conceptual framework for safety culture: The Egg Aggregated Model (TEAM) of safety culture. *Safety Science*, *103*, 323-339. https://doi.org/https://doi.org/10.1016/j.ssci.2017.12.021

Wansink, B., Painter, J. E., & Lee, Y. K. (2006). The office candy dish: proximity's influence on estimated and actual consumption. *International Journal of Obesity*, *30*(5), 871-875. https://doi.org/10.1038/sj.ijo.0803217

Wiegmann, D., & Shappell, S. (2001). APPLYING THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) TO THE ANALYSIS OF COMMERCIAL AVIATION ACCIDENT DATA.

Wilson, A. L., Buckley, E., Buckley, J. D., & Bogomolova, S. (2016). Nudging healthier food and beverage choices through salience and priming. Evidence from a systematic review. *Food*

Quality and Preference, *51*, 47-64.

https://doi.org/https://doi.org/10.1016/j.foodqual.2016.02.009

Zou, X., & Savani, K. (2019). Descriptive norms for me, injunctive norms for you: Using norms to explain the risk gap. *Judgment and Decision Making*, *14*(6), 644-648. https://doi.org/10.1017/S1930297500005362