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Nudging safety behavior in the steel industry: Evidence from two field studies

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ABSTRACT

The practice of nudging received much attention in different domains of human behaviour (e.g. finance, health, traffic safety and sustainability), but its relevance has not been systematically investigated for safety in the process industry. This study aimed to investigate the effectiveness of nudge interventions in promoting safety behavior in the steel industry through field experiments in a large steel plant, particularly in relation to gas hazards and falling from stairs The results of both experiments showed that the nudge interventions were very effective in promoting safety behavior among workers. An icon reminding of the gas dangers on work jackets effectively increased gas detector compliance, while hand print cues were able to promote workers holding onto handrails. Related organizational implications for a safety nudging approach are discussed. Overall, these findings suggest that nudge interventions can be a cost-effective approach to promote safety behavior in the steel industry. The suggested nudge framework should be implemented as part of a holistic safety approach to promote safety behavior among workers and prevent severe accidents.

Unsafe working environments imply a great human and economic cost. Starting in the fifties of the previous century, safety awareness has risen and incident rates in the process industry have known a remarkable decrease thanks to the introduction of improved technologies and safety standards. In the seventies, an increased focus on risk assessment and mitigation followed (Hudson, 2007), most often approached by a more technical perspective. Although these interventions were able to significantly reduce the amount of accidents (CDC, 1999; Weeks, 1991), much room for improvement remained, and an additional focus on safety behavior and the safety culture was needed. How to effectively change the unsafe behavior of the employees still remains a complex issue and is raised by several experts as the last remaining challenge to resolve (Hopkins, 2006; Knegtering & Pasman, 2009; Lindhout & Reniers, 2017; Reason, 2009). Although concepts as 'prevention through design' might reduce accidents in some parts of the industry, a change in unsafe behavior would be able to eliminate nearly all occupational accidents. Therefore any further reduction of the accidents would require a more thoroughly understanding and control of the underlying behavioral component of safety (Bhattacharjee et al., 2011; Krause, 2001; Talabi et al., 2015). Research shows that up to 90 % of the occupational accidents are human error related (Kletz, 2001). Addressing the human behavioral factor is therefore the biggest challenge for safety management today.

In the last decades, studies have brought new insights in human behavior, showing that people do not always act logically and with consideration, nor that they always make decisions in a fully rational way (Kahneman, 2011; Simon, 1955). The conception that people are 'boundedly rational' in turn led to the idea that people may benefit from a behavioral context that exploits automatic and suboptimal behavioral biases. This includes the implementation of subtle behavioral pushes, known as 'nudges', that strategically change the choice architecture (i.e., the physical, social and psychological aspects of the context that influence our choices, Thaler et al. (2012)) to change behavior, instead of focusing solely on rules, economic incentives, knowledge transfer and training (Thaler & Sunstein, 2008). Here, we want to apply the core insights of bounded rationality within behavioral science to industrial safety behavior, which to this day remains little explored (Lindhout & Reniers, 2017).

This unique field study takes place in a large Belgian steel plant, that is familiar with the evolution and the current challenges concerning safety in the process industry. Although the incident rate dropped significantly over the years following classical and state-of-the-art safety

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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

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

approaches, their efforts seemed to have reached a plateau of a seemingly non-reducible amount of safety incidents. In this study, we aim to investigate whether nudge interventions and choice architecture constitute an effective and supplementary safety management tool that complements the current classical safety approach. To this end, we developed and tested nudge interventions in safety domains that frequently encounter incidents in the steel industry, namely fall and gas hazards.

1. Two systems of decision-making and nudge theory

Actions can stem from deliberate, conscious reasoning or from automatic, unconscious responses triggered by the environment. Kahneman (2011) terms this distinction as 'System 1 and System 2 thinking' or the dual-process theory of decision-making. System 1 involves fast, instinctive, and unconscious decision-making, driven by subconscious values and beliefs, such as quick answers to simple math problems or associating red with aggression (Tham et al., 2020). On the other hand, System 2 is a more rational, deliberate thinking process, requiring conscious effort and attention, such as remembering something or comparing product prices. Both systems are typically active, with System 1 providing constant automatic responses, while System 2 engages in more complex or unplanned situations.

Thaler and Sunstein (2008) put forward the practice of 'nudging', meaning literally 'to give a little push', as a way to leverage bounded rationality. They suggest that people may be guided and supported in making the right decisions by subtly altering the choice architecture in which the behavior occurs. Examples are the use of smaller plates, which lowers the amount of (unhealthy) food consumption (Wansink & van Ittersum, 2013) or painting colorful footprints on the ground towards stairs to lower elevator use (Van Hoecke et al., 2018). Importantly, individuals retain the freedom of choice, but typically behavior changes as a function of simple, and often cheap, targeted choice architecture interventions. Nudge interventions have been studied and implemented successfully in several domains including health and wellbeing, financial decisions, energy efficiency, eating behavior, work performance and so forth (Castleman & Page, 2015; Hanks et al., 2012; Johnson & Goldstein, 2003; Schultz et al., 2007; Thaler & Sunstein, 2008; Torgler, 2004).

1.1. The effectiveness and cost-effectiveness of nudge interventions

Hummel and Maedche (2019) conducted a review of 100 primary publications and found that 62 % of experimentally tested nudges had statistically significant effects on behavior, with a median effect size of 21 %. Similarly, a recent *meta*-analysis by Mertens et al. (2022) including over 200 studies and 450 effect sizes reported an overall small to medium effect size for nudge interventions (Cohen's $d = 0.45$). Some studies call for caution, including those from governmental nudge units (DellaVigna & Linos, 2022) and those that controlled for publication bias (Maier et al., 2022), and suggest that actual expected effect sizes may be lower. Hallsworth (2022) adds emphasis on the importance of assessing the effectiveness of nudges in specific contexts to avoid drawing general, but inaccurate conclusions.

The cost-effectiveness of nudges is another advantage of this approach. Benartzi et al. (2017) report return on investment (ROI) ratios for nudges that ranged between 10 and 100 for every invested dollar, compared to 14.68 for campaigns and 1.24 for tax incentives. Nudge interventions can therefore be of great value in improving the cost-effectiveness of behavior change programs in public and private organizations, including safety management. Besides the financial ROI, they are also often easy to apply and implement.

The practice of nudging sparked a debate on ethical implications, as it often involves covertly influencing behavior without consent (Lin et al., 2017). Recurring objections to the practice are that it is based on paternalistic grounds, it is a threat for an individual's autonomy, and it is unclear in whose interest the choice architects operate (Grüne-Yanoff & Hertwig, 2016; Hansen & Jespersen, 2013). In response to these objections, Sunstein (2015) states that it is pointless to object to choice architecture or nudging as such, as choice architecture cannot be avoided. Either situation influences towards one behavior or another. It is reasonable to worry about or object to particular nudges, but not to nudging in general. Secondly, he argues that from an autonomy and welfare point of view nudge interventions are actually required. This because other interventions such as bans, taxes or other traditional interventions often impact an individual's autonomy more than nudge interventions do. In their FORGOOD framework, Lades and Delaney (2022) propose seven ethical dimensions to consider when developing nudges, including fairness, openness, respect, goals, opinions options and delegation. Typically, the practice of nudging is considered legitimized when behavioral freedom is preserved and when the outcomes benefit both the influencer as the person who is being influenced (Sunstein, 2015). In the case of work health and industrial safety, this is more straightforward, as employer and employee interests are aligned, towards the safety of the employee. Yet, for industrial applications, an ethical board should guard the ethical appropriateness of suggested objectives, nudge formats and associated observation methods. Also, it is important to engage employee representatives (e.g. unions) in the decision process, as was also done for this study.

1.2. Taxonomy of nudge interventions

A plethora of toolkits (e.g., MINDSPACE, EAST) and nudge classifications exist (e.g., Hummel and Maedche (2019), Beshears and Kosowsky (2020) and Hansen and Jespersen (2013). While they all provide their own unique contributions, one of the most comprehensive, yet uncluttered taxonomy of nudge interventions is the one developed by Münscher et al. (2016).

Münscher et al. (2016) categorize nudges, also known as choice architecture interventions, into three clusters, each targeting specific psychological barriers and encompassing various techniques (see Fig. 1) (Mertens et al., 2022). The first cluster, 'decision information', leverages decision-related information by increasing its availability, comprehensibility, and personal relevance. Techniques include providing social reference information, like social norms, to reduce ambiguity and guide appropriate behavioral responses. For instance, a study by Allcott (2011) showed that households receiving letters comparing their energy consumption to similar neighbors reduced usage by 2 %, comparable to the impact of traditional financial interventions. Other techniques in this cluster involve providing (direct) feedback (Cappa et al., 2020) or rephrasing informational messages in more simplified and personally relevant formats (Cappa et al., 2020; Mills, 2022).

The 'decision structure' cluster leverages the context-dependency of decision-making by modifying the format or arrangement of choices. Notable techniques include changing defaults, such as opt-out organ donor policies that significantly increase donor rates (Davidai et al., 2012). Crucial seems to be the effort people are willing to put into making the right decisions or the lack of interest in changing automated actions (e.g., defaults) they do not consider important or are not even aware of. Techniques altering decision structure also include changing effort through friction modification (e.g., increasing elevator waiting time to promote staircase use) and manipulating the order of choices or using decoys (Stoffel et al., 2020).

The final cluster, 'decision assistance,' addresses the intention-behavior gap by reinforcing self-regulation. Techniques include reminders, such as text messages before medical appointments to boost vaccination rates (Milkman et al., 2021), and commitment facilitation, where, for example, pre-commitment to future retirement savings significantly increases savings rates (Thaler & Benartzi, 2004). This taxonomy facilitates the strategic development and implementation of multiple nudges, targeting specific psychological drivers or barriers for improved decision-making.

2. Nudging and choice architecture in the domain of safety

Nudging applications in the domain of safety are limited in quantity as compared to other application areas such as health, economic decision-making and sustainability (see *meta*-analysis of Mertens et al. (2022) for an overview). The studies that do relate to safety are mainly situated in the domain of traffic safety (Avineri, 2014; Goldenbeld et al., 2016). An example of a successful safety nudge in the domain of traffic is the use of 'speed reduction markings' (National Academies of Sciences, Engineering, and Medicine, 2008), which are progressively narrower painted white lines that create a visual illusion of acceleration, prompting drivers to lower their speed (Thaler & Sunstein, 2008). Other examples are the use of personalized feedback to improve driving performance (Choudhary et al., 2019), or the use of salient seatbelt reminders (Lie et al., 2008).

While various common safety interventions in the process industry could classify as nudges, such as signalization or warning signals, very few to no studies have investigated the potential of nudge interventions for industrial safety as a distinct and complementary safety approach (Lindhout & Reniers, 2017). This is confirmed by a recent literature review of choice architecture applications in the construction industry (Sarpy et al., 2021) that found sparse nudge studies in the construction sector or related industrial sectors (e.g., farming and manufacturing). One study by Luria et al. (2008) found that visibility in the workplace moderated the level of manager-employee interaction after a supervisor coaching session, which in turn led to a greater compliance with ear protection. Another study by Rice et al. (2022), found that sending text messages could promote the amount of performed toolbox talks (i.e., short safety talks) in construction. A last study by Zohar et al. (1980) in a steel plant, found that the use of direct feedback of temporary hearing loss, by showing hearing capacity graphs before and directly after shifts in noisy departments, was able to increase the compliance rate of wearing earplugs from 40 % to 85 %. The adoption of a nudge framework could both enhance the categorization of previous safety interventions that address the same psychological barriers, and stimulate the development of new safety interventions that complement and extend previous findings.

Lindhout and Reniers (2017) propose exploring nudging as a novel industrial safety tool, identifying improvement areas in industrial risk-taking. They distinguish between deliberate unsafe acts (e.g., considering rules unnecessary) and those stemming from automatic decision-making (e.g., memory lapses due to fatigue). In doing so, they take into account the role played by the management that enable unsafe choices (e.g., economic priority, poor instructions or lacking awareness). This approach aligns with safety models like the Swiss Cheese Model (Reason, 1990) and the Human Factor Analysis and Classification System (HFCAS) (Shappell & Wiegmann, 2001; Wiegmann & Shappell, 2003), recognizing various causal layers for accidents (i.e., organizational, environmental, personal, etc.) and the role of intention in separating error from violation. This aligns with the fundament of the choice architecture taxonomy (Münscher et al., 2016) that built its clusters around trying to overcome the intention-behavior gap or to influence the intention for the better. It should be noted that nudges will not always be able resolve safety concerns stemming from flawed procedures or inaccurate instructions provided by team leaders. In general, nudges may aid in promoting better adherence to safety rules, given that the rules themselves are deemed appropriate.

3. Current study

The Belgian steel plant involved employs over 5000 employees and processes raw materials to steel coils and refined products via a chain of coordinated factories, including cokes plants, blast furnaces and sinter plant, hot- and cold rolling mills, galvanization lines and tailored blanks facilities. Although the safety standards at the industrial plant are rather high, a couple of thousands of incidents (i.e. near accidents) still do occur at their sites. These incidents align with the specific safety domains that typically account for the largest proportion of accidents (up to 75 %) in the heavy industry, including working at height, handling heavy loads, contact with moving machine parts, gas hazards and traffic safety (Lindhout & Reniers, 2017; RIVM, 2016). The current safety approach prioritizes technological innovation, upgraded Personal Protective Equipment (PPE), enhanced protocols and comprehensive employee training (e.g., handling unexpected crises). Advisors monitor safety and protocol compliance, and focused training targets influential employees to foster shared vigilance and enhance the safety culture. With the current interventions primarily targeting deliberate decision-making (system 2), there is recognition of the need for additional interventions addressing more automatic responses (system 1) and cognitive limitations to surpass the safety plateau.

We carry out two field experiments in this large steel plant to evaluate the effectiveness of nudge interventions as part of a holistic safety approach. We select two out of the five safety domains that typically account for the most safety accidents: including gas hazards and staircase safety (as part of working at height). The first aim of this study is to evaluate the effectiveness of nudge interventions in promoting gas detector compliance (RQ1), which is a crucial element in preventing gas hazards (Hall et al., 2021). The second aim is to investigate if nudges prove useful in mitigating unsafe behaviors involved in staircase safety (RQ2). Staircase safety is not only relevant in the process industry or for working at height, slips, trips and falls also account for one of the largest proportions of occupational accidents in general (European Agency for Safety and Health at Work, 2022).

4. Experiment 1

Gas hazards play a critical safety role in the process industry and the steel industry. These industries deal with various gases, some of which can be highly flammable, toxic, or explosive (Eckhoff, 2006; Linnerud et al., 1998). Gas hazards refer to any gas or vapor that can pose a risk to human health, safety, or the environment (Khan & Amyotte, 2002). The aim of the first experiment was to evaluate the effectiveness of nudge interventions in promoting gas detector compliance, therefore mitigating dangerous exposure to potential gas hazards.

Gas detectors are part of the critical personal protective equipment (PPE) in areas where gas is present. Yet, is it known that PPE compliance can be a hassle in the process industry for various reasons (e.g., workers considering the PPE unnecessary or impractical, the lack of clear guidelines and difficulties to monitor compliance on large industrial plants) (Man et al., 2021; Vukicevic et al., 2022). Although the danger of gas poisoning is a strong enough argument for many to respect precautionary measures, typically we see workers habituating to risks (Lee & Kim, 2022) and other behavioral drivers that lead to suboptimal gas detector compliance (i.e., memory lapses due to time pressure). The multinational steel producer involved in this study sees an incompliance of around 15 % in the most recent years at their Belgian sites (as found by frequent tallying samples collected on a yearly basis).

We conduct a field experiment to measure the effect of two different nudges on safety behavior. The experiment takes place in a blast furnace and sinter plant of the industrial site, which is an environment that is exposed to gas hazards on a continuous basis. We focus one on of the most prevalent and dangerous gasses in this area, namely carbon monoxide (CO), which is a colorless, odorless, and tasteless gas (Ernst & Zibrak, 1998). The main components of gas detector compliance we aim at include wearing the gas detector, activating it and wearing it at the right place (i.e., on the left chest at breath height). The proper calibration of gas detectors is also important, but is not targeted in this study because it would entail more intrusive observation with high risk of confounding the study results by increased participant awareness.

4.1. Behavioral techniques and hypotheses

A round of informal interviews (n = 10) two months before the start of the experiment reveal that most employees claim to be aware of the risk involved, but mainly forget to wear or activate the detector when they do not comply with the rules. In addition, they state that it is not always clear where the appropriate place for the detector is (e.g., on helmet, jacket or pants) and that it is not always clear where the more gas hazardous areas are. Therefore, our nudge interventions aim to assist in making safety choices, within Münscher et al. (2016) their cluster Decision Assistance. Relevant behavioral techniques and nudge concepts to promote gas detector compliance include reminders, priming, feedback, social norms and commitment.

First, cue-based reminders play a vital role in assisting individuals prone to forgetfulness amid daily distractions. Rogers and Milkman (2016) emphasize their superiority over written or electronic reminders, underscoring their underappreciation.

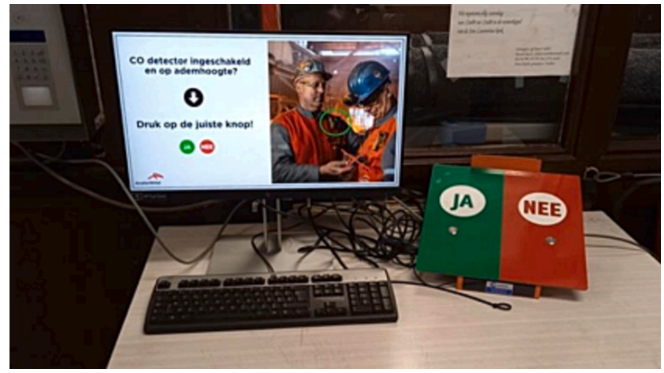

Fig. 3. Push buttons nudge.

Second, the concept of priming, as explored by Bargh and Chartrand (2000), reveals how initial exposure to a stimulus can influence subsequent responses. Contextual changes, such as altering colors, can evoke distinct emotional and behavioral reactions, as highlighted by Tham et al. (2020).

Third, providing direct feedback can help to inform employees when they are not in order with their PPE's; similar to digital speed signs in traffic informing on the adequacy of speed (Gehlert et al., 2012). This relates to providing information for social comparison, which causes the greatest behavior change in the domain of climate change mitigation behaviors (d = 0.370), surpassing financial incentives (d = 0.317) (Bergquist et al., 2023).

Fourth, social comparison heavily relies on social norms, reflecting the substantial influence of others' actions and values (Bicchieri, 2017). This holds true in the workplace, where strategic use of social information can nudge employees towards better PPE compliance by showcasing positive examples and limiting the visibility of non-compliance (Newaz et al., 2019).

Lastly, pre-commitment strategies, successful in pension saving programs like Save More Tomorrow (Thaler and Benartzi, 2004), assist individuals in adhering to their intentions. Workers in general state to be aware of the high risk of gas hazards and their willingness to comply. The emphasis here is on supporting workers in following through on

Fig. 4. Icon nudge ('CO-detector here!').

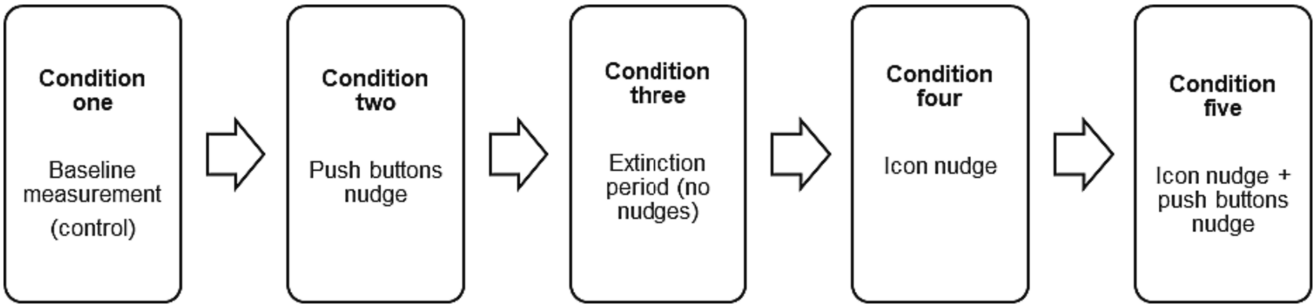

Fig. 2. Within-subjects design of nudge implementation (3 weeks per condition, except for the baseline measurement that lasted 6 weeks).

intentions and strategically influence risk perception, that can diminish over time (Lee & Kim, 2022), to promote safety behavior (cf. 'Decision assistance').

Here, we will test the potential of a combination of the approaches above. The push buttons nudge intervention focuses on integrating commitment strategies and elements of (social) feedback, and is expected to have a positive effect on wearing, positioning and activating the detector (Hypothesis 1). This nudge includes a setup with a digital screen stating 'CO detector activated and at chest height?', accompanied with red and green push buttons (Fig. 3). The screen also shows how many colleagues previously pushed the green button. The aim is to let people commit to a certain behavior, increasing the motivation to follow through with their intention, which can be amplified by seeing the good example of previous colleagues (i.e., social proof). Displaying information on the actions being adequate (green button) or dangerous and unaccepted (red button) provides clear feedback that assists in directing appropriate subsequent actions (i.e., activating and wearing detector correctly).

The second, icon nudge is a red triangle shaped icon placed at the jackets at chest height stating 'CO detector here!' with a little skull symbol on top (Fig. 4). It serves as a visible reminder, including priming features to influence risk perception, and is expected to increase the amount of people wearing gas detectors (Hypothesis 2a). The reminder is continuously active and visible when detectors are not worn correctly. When detectors are worn properly, the icon becomes invisible. This ensures the reminder's presence only when necessary, preventing the extinction of its effect. The approach aligns with shared vigilance for safety, allowing colleagues to easily identify non-compliance and serving as a reminder for them to address the issue as well. The use of a skull and red triangle is expected to prime negative affect (Kareklas & Muehling, 2014; Pravossoudovitch et al., 2014; Tham et al., 2020), inducing feelings of unsafety and anxiety, positively influencing the perceived risk (Slovic et al., 2005). We expect the effect to be similar on the various aspects of wearing the detector correctly, being wearing it at the right position and activating it (Hypothesis 2b).

The effect of both nudges is expected to be significant, but small (Hypothesis 3). Which in itself is not a problem, because of the high cost-efficiency of nudges and the difficulty of achieving any behavioral change for the safety domain at hand (any marginal increase is highly welcome).

5. Method

5.1. Participants

This experiment takes place in a blast furnace and sinter plant of the industrial plant, forming one joint department, where 85 blue-collar employees work. All internal workers are included in the experiment. These workers are all Dutch-speaking men. The average age is 33.08 years (SD = 10.85) and the average level of seniority is 10.26 years (SD = 9.53). The workers either worked in a rotating shift system (6 h-14 h, 14 h-22 h, 22 h-6 h, and a fourth shift was free of work), or in a day team (9 h–17 h). We set up two observation moments per week for each shift and the day team.[1] This way, there are eight observation moments per week and almost all 85 participants, except those that were in the 'free of work'-shift, were tallied weekly. For the number of observations, we are dependent on the goodwill and time of the line managers, the foremen and the participants, as well as time constraints. A power analysis conducted, using G*Power, assured that we would have more observations (n = 963) then needed (n = 848) to find an expected odds ratio (OR) of 1.5, which is a small effect size (Sánchez-Meca, 2003). This aligns with the general conception in the literature that nudges commonly have a smaller effect size (DellaVigna & Linos, 2022). 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 free accessible for the employees on the intranet website of the steel plant. Ethical clearance for this study is provided by the safety department and labor unions of the industrial plant.

5.2. Research design

The first experiment has a within-subjects design (see Fig. 2). All 85 participants are exposed to the same safety nudges in the same subsequent conditions. In the first condition, a baseline measurement of the safety behavior is performed, during which no safety nudges are implemented. In the second condition, the participants are exposed to the first safety nudge. In the third condition, this first nudge is removed during an extinction period. With this extinction period, we want to minimize the impact of the previous intervention on the next one. After this period, all participants are exposed to the second safety nudge in the fourth condition. In the last phase, the fifth condition, participants are exposed to both safety nudges at the same time. The order of conditions is the same for all participants, as the industrial plant only allows one intervention site, and work schedule and operational demands applied. Additional extinction periods were intended after the fourth ('Icon nudge') and the fifth condition ('Icon nudge + push buttons nudge'), but did not proceed due to unplannable operational demands and organizational constraints, so that a fully (counter-)balanced design was not possible.

5.3. Materials and procedure

Measures and observation method. Safety behavior in this experiment refers to the correct usage of the personal CO-detector by blue-collar workers at the blast furnace and sinter plant. This safety behavior consists of two actions. Firstly, the CO-detector has to be worn

[1] Collecting clustered data is difficult given the simultaneous presence of multiple teams and would require too intrusive observation methods to tell them apart (e.g., repeated questioning by observers or changing visible work wear per team). Therefore, the group of participants is treated as a homogenous group.

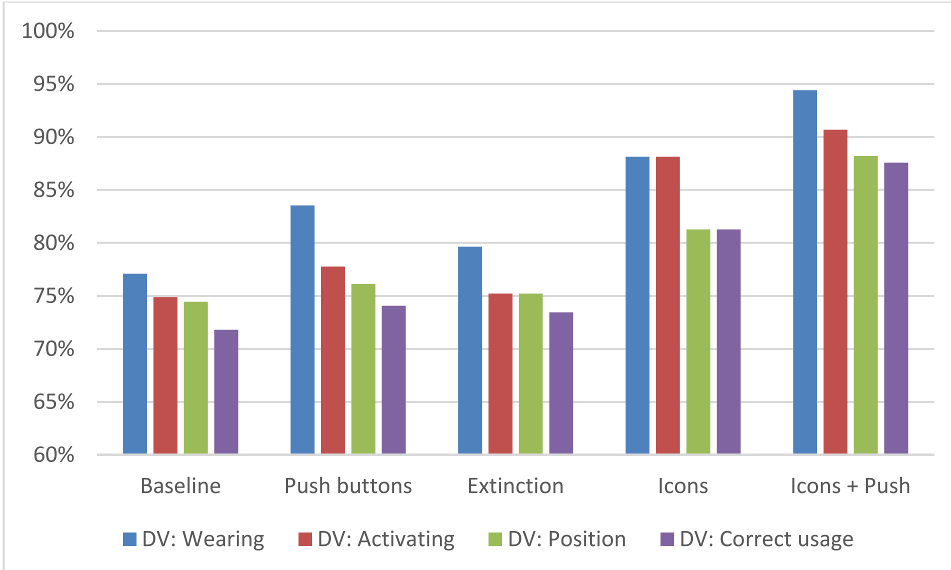

Fig. 5. The percentage of correct usage of the CO-detector among control and test conditions.

in the right place (on the left chest at breath height). Secondly, the CO-detector has to be activated. The dependent variables include 1) whether people carry the CO-detector (' Wearing detector'), 2) if the detector is activated ('Activating detector'), 3) the proper placement on the body ('Position detector') and 4) full compliance, which entails wearing the activated detector at the right place ('Correct usage). To investigate the safety behavior, on-site observations are organized in the work place (i.e., where they should comply with the CO detector guidelines). Alternatives such as reading out data of the individual CO-detectors, using camera footage or self-reports are considered, but they are not included due to increased risk of socially desirable behavior, inaccurate measurements and/or privacy issues or adverse reactions. The on-site observations are conducted twice a week by foremen of each of the teams (the different shifts and the day team) using structured and standardized forms developed in collaboration with field experts (see Table A1 in appendix). Every observer receives a training including a clear explanation of the objective, explanation of concepts on the observation form and practical guidelines to observe in a non-intrusive way. They are told that random double-checking can take place at any time to monitor tallying accuracy. The observers are instructed to observe between the start of the shift and the first subsequent break. The forms are filled out shortly after the observation, aiming to preserve the subtlety of the observations, and registered in Excel. The observers do not collect any personal data to ensure the anonymity of the workers. At the end of every month, both the anonymous observation forms and Excel files are sent to the researchers, allowing to control for data-entry errors. To limit potential confounding influences, the participants are told two months upfront that a general safety study would take place requiring data from multiple safety domains (incl. gas hazards), without further details. The temporal delay (i.e., 2 months), vague study description and clear instructions for subtle observations (e.g., strategic places, not standing still for too long, while talking, etc.), keep potential unwanted influences of in-person observations to a minimum.

5.4. Nudge intervention procedure

Push buttons nudge. The text on the display says: "CO-detector activated and at chest height? –> Press the correct button!". The green button says 'yes', and the red button says 'no'. Also, an image of a worker with the correct placement of his activated CO-detector is shown. The display is placed at the exit of the shared cafeteria area, which all workers pass going back to work. Once they pass through this door, they should wear a CO detector, entering a potentially dangerous zone. It is here were observers check if they comply with safety rules or not (i.e., after interacting with the machine). Thus when leaving the cafeteria area, the workers have to push the button that indicates their behavior. When pressing green, the worker get this feedback message on a green screen: "Congratulations! You are well-protected!"; plus they see the real number of how many previous colleagues pushed the green button. When pushing red, the worker get this feedback message on a red screen: "You are in danger!"; the amount of people pressing the red button is not displayed to prevent reversed social effects.

Icon nudge. The icon nudge, a warning triangle plus text ("CO-detector here!"), is attached with hook-and-loop fasteners on the work wear of the workers at chest height. Attaching the icon with hook-and-loop fasteners on the outfits of all 85 participants, was done by a warehouse worker.

Both nudges are developed collaboratively with the safety experts. While the researchers propose innovative ideas using behavioral insights, based on informal interviews and observations, the safety experts monitor feasibility and fit with existing procedures. Labor unions are involved throughout the process, to evaluate the ethical appropriateness of the suggested nudges (cfr., FORGOOD ethical framework) and associated observation methods.

5.5. Data-analysis

To answer the hypotheses of the first experiment, multiple binary logistic regression analyses on the dichotomous variable counts are conducted. This type of analysis is suitable to examine the effect of multiple predictors (i.e., different experimental conditions) on binary variables (i.e., the correct usage of the CO-detector, tallied in different aspects). The logistic regression coefficients are used to calculate the OR which is an effect size measure that quantifies the association between two binary variables. It represents the odds of an event occurring in one group compared to another group. The OR is calculated by dividing the odds of the event occurring in one group by the odds of the event occurring in the other group. The OR can range from zero to infinity, with a value of one indicating no association between the two variables, a value above one indicating a positive association, as opposed values below one that represent a negative association. In general, the magnitude of an OR can be classified as small (1.5), medium (2.5), or large (4) (Chinn, 2000; Hasselblad & Hedges, 1995; Sánchez-Meca et al., 2003), although different fields and differences in the base-rate may imply

Table 1
The effect of the nudges on gas detector compliance.

Variables	Wearing Detector		Activating Detector		Position Detector		Correct Usage	
	Exp (B)	*d*	Exp (B)	*d*	Exp (B)	*d*	Exp (B)	*d*
Push buttons	1.51* (1.754)	*0.23*	1.20 (0.846)	*0.10*	1.10 (0.423)	*0.05*	1.10 (0.452)	*0.05*
Push buttons (extinction)	1.16 (0.535)	*0.08*	1.04 (0.154)	*0.02*	1.04 (0.154)	*0.02*	1.09 (0.319)	*0.05*
Icon	2.21*** (3.021)	*0.44*	2.55*** (3.618)	*0.52*	1.93*** (2.720)	*0.36*	1.71** (2.344)	*0.29*
Icon - Push buttons	5.02*** (4.271)	*0.89*	3.34*** (3.879)	*0.67*	2.57*** (3.273)	*0.52*	2.77*** (3.626)	*0.56*
Observations	963		963		963		963	

Note. z-statistics in parentheses; *** p <.01, ** p <.05, * p <.1; reference level for interventions 'Control – Baseline measurement'.

different interpretations (Chen et al., 2010). Also, the Cohen's d is calculated to interpret the effect sizes (i.e., $d = 0.2$ small, $d = 0.5$ medium and $d = 0.8$ large). All analyses are performed in IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, N.Y., USA).

6. Results

During the 18 weeks of safety behavior observations, in total, we collected 1006 individual observations, of which 963 are included in the analyses. 43 observations are excluded since it was not clear if those data belong to internal workers or external contractors.

6.1. Push button nudge (+extinction)

Based on the recorded data, we find out that in the push buttons nudge condition many workers pushed the buttons (2455 times on the green and 678 times on the red button, see details in appendix Table A2). This is a manipulation check to see whether workers actually do use the push buttons nudge. The aforementioned numbers show that this is the case. The results of the binary logistic regression analyses indicate that the push button interventions has a small significant effect on the wearing of the gas detector (OR 1.51, p <.1), but not on the other outcome variables (i.e., activating or position of the gas detector), when compared to the baseline condition (i.e., control without nudges). We do not find a significant increasing trend of the effect with the weeks passing by, which one could expect with the display of a continuously rising number of previously complying colleagues (cfr., social norms). When we take a closer look to the subsequent extinction period (i.e., removal of push buttons nudge); we see that the significant effect on the wearing of the detector disappears and that no significant effects are found on the other outcome variables. See Fig. 5 for the compliance ratios in percentages by condition.

6.2. Icon nudge

The results of the logistic regression analyses indicate that the icon nudge has a medium effect on the wearing of the detector (OR 2.21p <.01) and activating it (OR 2.55, p <.01), compared to the baseline condition (i.e., control condition without nudges). On the other hand, it had a rather small effect on the position of the gas detector (OR 1.93, p <.01) and the completely correct usage (i.e., wearing at the right place and activated) (OR 1.71, p <.05). These results indicate that the workers are clearly more likely to wear the gas detector and activate the gas detector when the icon nudge is present (versus the absence of the nudge), but that they are only slightly encouraged to wear the protector at the right place; which ultimately reduces the nudge effect on full compliance.

6.3. Push buttons and icon combination

Besides evaluating the effect of the nudges individually, we also look at the combination of both nudges implemented simultaneously in a distinct experimental condition. Again, binary logistic regression analyses are conducted to evaluate the effect of the combined nudge condition on the binary outcome variables (i.e., wearing the gas detector, activating it and the right placement on the chest), compared to the control condition without nudges. The results indicate that the nudge combination have a large effect on the wearing of the gas detector (OR 5.02, p <.01), a medium to large effect on the activation of the detector (OR 3.34, p <.01) and a medium effect on both the right placement of the detector (OR 2.57, p <.01) and on being fully compliant (OR 2.77, p <.01). It appears that the combination of both the push button nudge and the icon nudge results in workers being significantly more compliant with the CO-detector guidelines, as compared to when they are working in the absence of those nudge interventions. The combination of nudges also seems to elicit a higher significant effect on full detector compliance (OR 2.71, p <.01) relative to the icon nudge (OR 1.71, p <.05) and the push buttons nudge (which is insignificant) (see Table 1).

7. Discussion

The first experiment examines the influence of two types of safety nudges, namely the push buttons nudge and the icon nudge on CO-detector compliance. The push buttons nudge has a small significant influence on the wearing of the detector, prompting individuals to get one, but not on activating or positioning. Those already wearing the detector may lack the reflex to check activation or correct positioning, while those not wearing it potentially forget to attend to it during routine walks to the lending machine. An activating reminder at the lending machine could mitigate this oversight. Adding extra information after pressing the red button (e.g., importance compliance and repetition guidelines) could also potentially increase the effect. The push button effect did not significantly increase over the weeks, as one could expect from a proportionate social norms effect of displayed numbers (Cialdini et al., 1999). Potentially, the rapid initial growth (up to 500 in 4 days) led to higher insensitivity to further increases, given that people think in relative sense (Bushong et al., 2020).

While we were able to monitor the use of the push buttons to some degree with push data (finding a regular pattern over three weeks), future replications could aim to observe the action with cameras or a badging system to account for every individual independently. Using cameras could clarify, for example, if people adjust the detector before pressing, press red and adjust after, or do not interact at all. Moreover, there is confusion in the factory's gas detector guidelines. Some supervisors and prevention experts permit wearing the gas detector on the helmet, provided it is at 'breath height,' contrary to the formal requirement of wearing it on the chest. This ambiguity may prompt individuals to relocate the detector to inappropriate positions, such as pants, shoulders or helmet, as noted by some workers post-experiment. This indicates the importance of clarity in prevention guidelines and the consistency in supervision (Newaz et al., 2019). No effects are found in the extinction period after removing the push button nudge, indicating both that the nudge effect disappears after removal as that the mere succession of in-person observations is not a determining condition for the establishment of the effect.

Overall, the icon nudge is more effective on all outcomes (i.e., activation and placement) than the push button nudge. It appears that a reminder that is omnipresent in the workplace, resulting in more nudge exposure, can be more effective. In addition, it is likely that a higher level of interactions with and visibility of this nudge amplifies social influence through shared vigilance (Brizon & Wybo, 2006), which results a bigger effect on gas detector compliance. Also, the danger inducing icon (i.e., red triangle with skull) can contribute to a stronger corrective action via negative affect, as compared to the push button nudge that merely mentions 'you are in danger!' (Slovic et al., 2005). The priming effect of colors, including red as danger associations, is widely accepted (Pravossoudovitch et al., 2014; Tham et al., 2020), and increasing support is found for danger association of visual cues referring to death or dying (incl. skulls) to promote desired behavioral intentions (Kareklas & Muehling, 2014; Wogalter et al., 1995). Despite, our logical assumption between skulls and its relevance to gas hazard signaling should be further investigated. A tight time schedule did not allow us to pre-test the priming effect (i.e. comparing symbol with and without skull), but given the success of the intervention we advise to explore this in further research (e.g. online survey or lab study). The clear visual placement of the icon at chest height is assumed the reason for its significant effect on positioning, with the relatively smaller impact on position (compared to wearing) again being influenced by unclear prevention guidelines (i.e., breath vs. chest height).

The combination of both nudges has a medium to large effect on CO-detector compliance. This effect is larger than the nudges individually, which points at the additivity of nudge interventions. This finding aligns with previous studies in the nudge literature that show that often the effect of nudges interventions combined is larger than in isolation (Ayal et al., 2021; Brandon et al., 2019). This additivity is a promising answer to the critic of the rather small effect of nudge interventions as shown in recent *meta*-analyses (DellaVigna & Linos, 2022).

8. Experiment 2

Danger of falling from stairs is always present, especially in certain working environments and weather conditions. The cold-rolling pickling mill (CPM) at the industrial plant involved is a workplace dealing with a large amount of oil emulsion that coats surfaces, including the stairways, leading to a higher risk and amount of falling incidents. When taking the stairs, both technical (e.g., the height of the steps, the handrail, the material of the stairs, etc.) and behavioral factors play an important role (e.g., holding handrails and adjusting speed). In a preliminary observation at the CPM, we saw that up to 25 % of passers-by didn't hold the handrail when coming down the stairs. When asking a part of the group (n = 15) why they didn't hold the handrail, two months before the start of the experiment, they said it was for no particular reason; adding that it was presumably due to forgetting or by being in a hurry (cfr., economic time pressure). This is interesting in the light of 'nudgeability', as the lack of strong preferences often indicates a larger nudge potential (de Ridder et al., 2022).

8.1. Behavioral techniques and hypotheses

Some elements trying to increase the visibility of the footsteps for better foot placement (i.e., yellow markings footstep end; see Foster et al. (2014)) or to reduce the speed (i.e., gate at the top of the stairs) were already in place, so we focused on holding onto the handrail. The aim here is to create the intention and to remind people of the appropriate safety action, which apparently quickly escapes attention. Some behavioral techniques and concepts seem particularly interesting, including reminders, salience and priming.

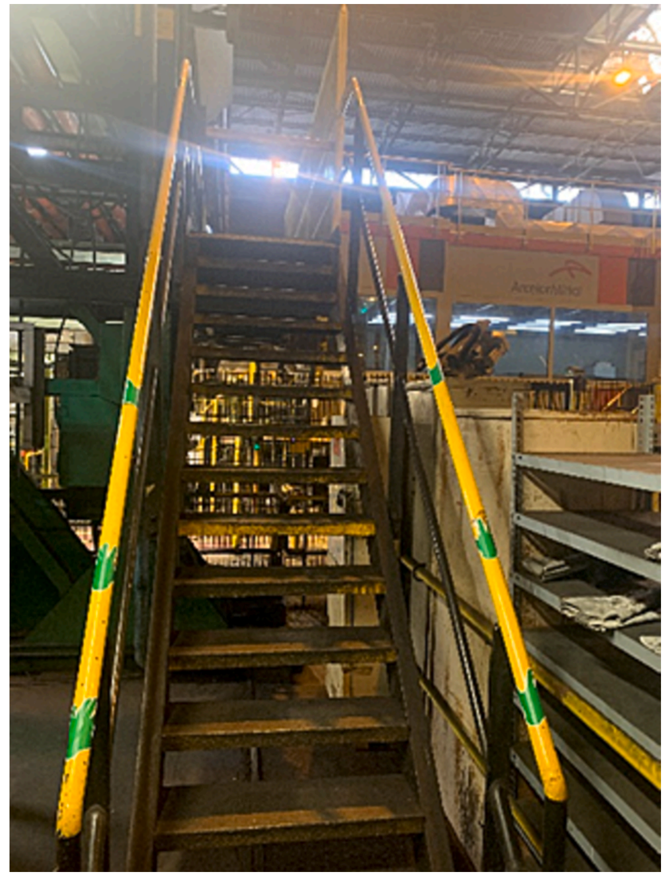

Fig. 6. Blue hand prints. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Reminders can help to focus on staircase safety, when workers attention drifts due to daily work related tasks. This reminder needs to be salient, which can be defined as the characteristic of something that stands out from its environment and draws the individual's attention (Taylor & Thompson, 1982). Aiming to focus on S1 processing, the use of text will and should be limited or absent, considering that this involves more cognitive effort (cfr., S2 processing) (Kahneman, 2011). As workers indicate that they are indifferent to using the handrail or not, a simple reminder can be sufficient to make them use it. This reminder would also signal again the risks and dangers involved. Priming can be useful to prime unconscious thought preceding specific actions. Either by the use of color or by using other (visual) cues that influence the intended behavior. For example, Bargh et al. (1996) found that prior exposure to words associated with elderly stereotypes, led to participants walking slower towards the elevator upon leaving the laboratory.

The workers stated in their informal interviews that they are largely indifferent to holding the handrail or not, and most likely forget it or do not think about it when they do not use it. Therefore, it appears that trying to elicit an intention and provide assistance to follow through with this intention would be the right approach, tapping into Münscher et al.'s (2016) clusters Decision Information and Decision Assistance respectively. Following this rationale, a variety of nudges is developed to promote workers holding the handrails. The general concept is a hand print sticker that is placed on the handrail, which serves as a salient reminder attracting attention to handrail (Figs. 6 and 7). The hand shape is meant to be an action cue that clearly indicates what action needs to

Fig. 7. Green hand prints. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

be performed; being it through low effort conscious and potentially subconscious processing (i.e., hand shape activating subliminal relevant connections that stimulate the tendency to grab something). We believe that the use of reminders will significantly increase the amount of people holding the handrail (Hypothesis 4), and in line with nudge literature, a small effect is expected (Hypothesis 5).

We choose to test the execution of the hand stickers in two colors, being blue and green. A first consideration is to have sufficient contrast on the yellow handrails and the fact that blue is a color often used for safety signage (e.g., required PPE's). Another consideration is the potential priming effect that green could have to accentuate the action as being good and desired. Red would have been relevant, as this is linked to increased negative affect and higher perceived risk, but it can be confusing in the way that it can indicate that people should 'not' grab the handrail (e.g., warning) or that it is forbidden. In addition, green spheres are tested to see if the hand shape of the intervention is determining for its effect; controlling for a mere salient colored cue that draws attention to the handrail being sufficient to install the effect. The effect of the reminder is expected to be different as the composition of the reminder changes (e.g., color and shape) (Hypothesis 6).

A relevant aspect of evaluating the effectiveness of the nudge includes dividing the desired behavior into two parts, being 1) holding the handrail and 2) holding the handrail for the full length. The latter is, logically, the safest option and the optimal outcome. We expect a significant increase in people holding the handrail at full length, but the effect is likely to be lower than the increase in people holding the handrail partially (as holding the handrail can be seen as a mild form of cumulating effort, which people tend to avoid) (Hypothesis 7).

9. Method

9.1. Participants

This experiment takes place in a specific area of the CPM, with 3 dangerous staircases, where the internal workers (n = 118) have to pass by multiple times during a shift. All internal workers were included. This group exists predominantly out of males (n = 115) with only 3 females working in these departments. The average age is 44.27 years (SD = 10.49) and the average seniority adds up to 18.42 years (SD = 12.66). The total of workers is almost equally divided over 4 teams, including team A (n = 31), B (n = 28), C (=30) and D (n = 29).[2] Per staircase a distinct part of the participants (i.e., equally distributed amount, ranging between 37 and 39 individuals) uses one particular staircase, with limited use of the other staircases throughout the shift. The demographics of these subgroups[3] are very similar to one another and is not expected to influence the results. A large amount of observation is registered (n = 2412) in order to include all teams on an equal basis for the control and experimental conditions.[4] Before starting this study, approval was 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 free accessible for the employees on the intranet website of the steel plant. Ethical clearance for this study is provided by the safety department and labor unions of the industrial plant.

9.2. Research design

A mixed design is used including multiple within-subject conditions per staircase, varying from control to experimental nudge conditions, and between-subjects comparisons between the staircases. Different experimental conditions are tested at staircase 2 (i.e., blue hands[5]) than at staircase 3 (i.e., green spheres and hands), while staircase 1 served mainly as a control location. In week 5 an experimental condition was introduced at staircase 1 (i.e., blue hand prints) to check if the effect would hold on another location too. The blue hands condition at staircase 1 was implemented one week earlier than instructed, due to unforeseen maintenance of nearby installations at week 6, and the camera at staircase 3 went out of service due to technical problems, complicating a fully balanced design. Table 2 shows an overview of the research design and sequence of conditions.

9.3. Materials and procedure

Measures and observation method. The safety behavior included in this experiment involves holding onto the handrails, partially or for the entire length of the handrail. In addition, we controlled for the

[2] Team A (30 males 1 female; average age 47.45 (SD = 11.04); average seniority 18.16 (SD = 13.11)); B (27 males 1 female; average age 43.07 (SD = 10.47); average seniority 16.70 (SD = 13.04)); C (30 males female; average age 46.20 (SD = 10.25); average seniority 20.22 (SD = 12.18)); D (28 males 1 female; average age 41.49 (SD = 10.07); average seniority 19.38 (SD = 12.60)).

[3] Staircase 1 (37 males 1 female; average age 43.93 (SD = 10.32); average seniority 17.51 (SD = 11.47)); Staircase 2 (39 males 1 female; average age 41.58 (SD = 10.44); average seniority 19.62 (SD = 10.75)); Staircase 3 (37 males 1 female; average age 48.12 (SD = 9.86); average seniority 22.15 (SD = 11.73)).

[4] Collecting clustered data is difficult given the simultaneous presence of multiple teams and would require too intrusive observation methods to tell them apart (e.g., changing visible work wear per team). Therefore, the group of participants is treated as a homogenous group.

[5] We initially intended a 'blue spheres' condition preceding the first blue hands condition (staircase 2) to further disentangle the effects of symbol and color, but faced delay in delivery of the appropriate materials leading to a cancellation of this condition.

Table 2
Sequence of nudge implementations.

	Week 1	Week 2	Week 3	Week 4	Week 5
Staircase 1	Control	Control	Control	Control	Blue hands
Staircase 2	Control	Blue hands	Blue hands	Blue hands	Blue hands (+)
Staircase 3	Control	Control	Green spheres	Green hands	/

Note: 'Blue hand (+)' indicates a higher amount of blue hands on the handrail compared to 'Blue hands'.

direction ('upward' vs. 'downward'), time of the day ('morning' 5:30–6:30 a.m., 'noon' 12:30–2:00p.m. & 'evening' 9:30–10:30p.m.), speed ('slow' vs. 'fast', by estimation) and passersby being in group or not (≥2). Camera footage is used to observe to what degree passers-by comply with the handrail instructions for the three staircases. Two independent observers assess the footage. Every variable received a binary code, allowing a simple and direct data-input. Participants are informed two months upfront (to ensure forgetting) that a general safety study would take place requiring anonymous data-collection via camera-footage, without providing further details to limit confounding influences. Due to the time-consuming nature and the inability to observe multiple locations simultaneously without additional observers, in-person observations were deemed unsuitable.

9.4. Nudge intervention procedure

Following the sequence of the research design, polyester sphere and hand print stickers (i.e., green and blue) are placed at the handrails of the three staircases. The hand prints at the bottom of the handrail are directed upwards and at the top downwards (i.e., switching direction towards the middle) to align with the initial walking direction when approaching the stairs. We test the different effect of a lower (3 bottom and 3 top stickers per handrail, 12 for both sides) and higher amount of hand prints stickers on the handrail (5 bottom and 5 top stickers per handrail, 20 for both sides). We choose for a minimum of three hands, top and bottom, to attract sufficient attention and install a base level of salience, and test a higher amount of hands, with a maximum of 5 for the given length of handrail (avoiding overlap), to see if increased salience will benefit the impact.

Similar to the first experiment, the nudges are developed collaboratively with the safety experts following the same procedure. Again, labor unions are involved throughout the process, to evaluate the ethical appropriateness of the suggested nudges (cfr., FORGOOD ethical framework) and associated observation methods.

9.5. Data-analysis

Multiple binary logistic regression analyses are conducted to evaluate the effect of the nudge interventions, given the binary values of the dependent variables (e.g., holding the handrail or not). The OR is used to interpret the effect sizes, together with the Cohen's d. All analyses were performed in IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, N.Y., USA).

10. Results

During this experiment, 2412 observations are collected and no observations are excluded for analysis.

10.1. Nudge interventions: Colored hand prints and spheres

The results of the logistic regressions show us that the blue hand print stickers have a small to medium significant effect on both holding the handrail and holding it fully, with an OR of 2.32 (p <.01) and 2.23 (p <.01) respectively, as compared to the baseline condition (i.e., control condition without nudges) (see Table 3). The higher amount of blue hands also has a small to medium significant effect on both outcome variables with an OR of 2.71 for holding the handrail (p <.01) and an OR of 2.34 for holding it along the entire length (p <.01). The green spheres show no significant effect on either of the outcome variables. The green hand print stickers on the other hand show equally a small to medium significant effect on both holding the handrail (OR 2.37, p <.01) and holding it fully (OR 2.41, p <.01). When assessing the long term effect of the blue hand stickers we still find the small to medium significant effect on holding the handrail, with an OR of 2.48 (p <.01), and on holding it across the entire length, with an OR of 2.10 (p <.1). See Fig. 9 for the compliance ratios in percentages by condition.

Table 3
The effect of nudges and other covariates on handrail compliance.

Variables	Holding handrail Exp (B)	*d*	Holding handrail fully Exp (B)	*d*
Blue hands	2.32*** (-7.179)	*0.46*	2.23*** (-7.018)	*0.44*
Blue hands (higher amount)	2.71*** (-4.72)	*0.55*	2.34*** (-4.293)	*0.47*
Green spheres	1.24 (-1.277)	*0.12*	1.23 (-1.079)	*0.11*
Green hands	2.37*** (-3.844)	*0.48*	2.41*** (-4.009)	*0.48*
Blue hands (long term)	2.48*** (-4.413)	*0.50*	2.10*** (-3.829)	*0.41*
Speed (fast)	0.99 (-0.081)	*−0.01*	0.87 (-1.077)	*−0.08*
Direction (downward)	1.39*** (-3.248)	*0.18*	1.51*** (-3.99)	*0.23*
Group	1.25* (-1.78)	*0.13*	1.48*** (-2.913)	*0.22*
Noon	1.05 (-0.393)	*0.02*	1.07 (-0.651)	*0.04*
Evening	1.13 (-0.969)	*0.07*	1.18 (-1.317)	*0.09*
Observations	2412		2412	

Note. z-statistics in parentheses; *** p <.01, ** p <.05, * p <.1; reference level for interventions 'Control', for speed 'Slow', for direction 'Upward', for group 'Not in group' and for time of the day 'Morning'.

10.2. Speed and direction

Besides looking at the mere effect of the nudge interventions on the safety behaviors, also other covariates are taken into account, including the speed and the direction that people are going. The speed of people is an estimate of the observer and is divided into two categories being 'fast' and 'slow'. Little confusion exists as the distinction between being in a hurry or not is mostly clear. The results show that no significant effect was found here of people going fast, compared to people going slow, on holding the handrail or holding it completely. We do find a small significant effect of people going downward, which shows that they are 1.39 more likely to hold the handrail (p <.01), and 1.51 times more likely to hold it fully (p <.01), compared to people going upward (see Table 3).

10.3. Group effects and time of the day

In addition, we are interested to see if people in group behave differently (i.e., a minimum of 2 persons or more) in comparison with individuals. We find a small significant effect showing that people in group were 1.25 times more likely to hold the handrail (p <.1), and 1.48 times to hold it fully (p <.01), relative to individuals (see Table 3). Lastly, we look for differences between different times of the day (i.e., morning, noon and evening). No significant effects are found here.

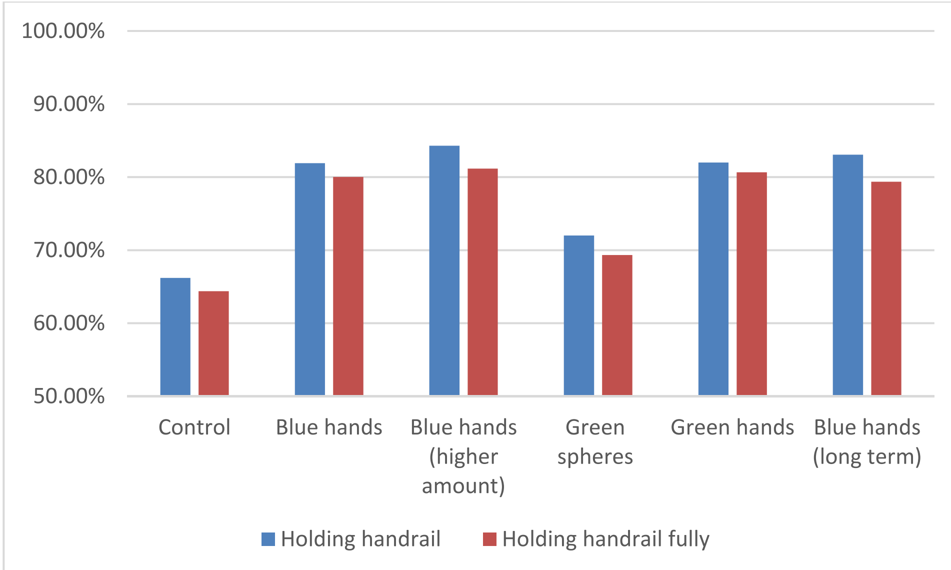

Fig. 9. The percentage of people holding the handrail among control and test conditions.

10.4. *Organizational factors*

In addition to the binary logistic regression analyses, another interesting finding originates from the observations. From the individuals that do not hold the handrail, up to 40 % has their hands full with material. Leaving no free hands to hold the handrail. Some examples of the materials involved boxes and pipes, personal protective equipment's (PPEs), work toolboxes and backpacks.

11. Discussion

We aimed to evaluate the effectiveness of nudge interventions on the safety behavior of people using staircases. The findings suggest that nudge interventions (i.e., reminders), such as blue and green hand print stickers, can have a positive effect on people's safety behavior on staircases. It is noteworthy that the effects are relatively small, but still significant and very cost-effective (i.e., nudge cost around 20 euro per staircase). The lack of significant effects of green spheres may imply that the hand shape is a determining factor (cfr., action cue); more than the priming color of the implementation (i.e., blue or green) (Tham et al., 2020). Using the color red could have a bigger effect on risk perception (Luximon et al., 1998; Pravossoudovitch et al., 2014), but can be confusing to interpret the required action (i.e., 'holding handrail desired or forbidden?'). It should be noted that placing hand prints stickers on 'all' stairs could contribute to a more rapid habituation, diminishing the salience effect (Hall & Rodríguez, 2017). A strategical use of the nudges by placing them on the most dangerous stairs (e.g., higher and bigger staircases as opposed to very small ones) is recommended, depending on the context at hand.

The valuable findings related to other covariates highlight the importance of considering the direction of travel, speed and the social context in which people use staircases in promoting safety behavior. The bigger nudge effect on going downward, which is more dangerous, likely reflects an activation of risk related thoughts, being it deliberately (cfr., System 2) or more subconsciously (cfr., System 1). The group effects can be explained through social influence, leaning towards conformity (Asch, 1956; Cialdini & Goldstein, 2004) and herd behavior (Bikhchandani & Sharma, 2000; Le Bon, 1899). Here we see that it was not just the difference in pace that influenced holding the handrail in group, as the effect holds for people in group using the staircase independent of the space between the passersby on the staircases. The study's finding that up to 40 % of people who did not hold the handrail had their hands full with material underscores the importance of considering organizational factors in promoting safety behavior on escalators. For instance, providing storage space and implementing policies that prevent people from using both hands to carry materials on stairs (e.g., elevators or two-person guideline), can increase the likelihood of people holding the handrail while using the stairs. This aligns with the HFCAS model of Wiegmann and Shappell (2003) that stresses the different layers that contribute to safety behavior, going from organizational to individual factors.

Importantly, we see that the significant nudge effect of the blue hands hold over a period of three months, with a limited decline, which is crucial in evaluating nudging as a safety management tool. Those medium to long term effect are less understood in nudging literature (Marchiori et al., 2017), making this is a promising result for (safety) applications 'in the wild' (Mazar & Soman, 2022). These insights can inform the development of interventions and policies aimed at promoting safety behavior on staircases, thereby reducing the risk of accidents and injuries, and their related costs (Chen et al., 2021; Gavious et al., 2009).

12. General discussion

Nudging has received a lot interest in the last decade, building on the work of multiple Nobel Laureates addressing the role of bounded rationality in human decision-making (Earl, 2018; Leahey, 2003). This vast amount of research is mainly concentrated in specific fields of research, including among others (behavioral) economics, health and well-being, and public policy (Dellavigna & Linos, 2022; Thaler & Sunstein, 2008). Little research is done in the domain of safety, except for traffic safety (Avineri, 2014; Goldenbeld et al., 2016), and almost no studies exist evaluating the nudge approach for industrial safety; despite its great potential (Kletz, 2001; Lindhout & Reniers, 2017). This study aimed to evaluate the potential of nudge interventions to promote industrial safety through two field experiments in the steel industry.

12.1. *Evaluating industrial safety nudges*

This study forms a starting point for an ongoing structured evaluation of nudge interventions to foster industrial safety. Our two field experiments provide evidence that small cost-efficient nudges can promote safety behavior in the domains of gas hazards and staircase safety. Especially the nudges that were omnipresent at the work place (i.e., the gas icon and hand shaped stickers), which resulted in a higher level of nudge exposure, seemed to be the most effective. This aligns with the complexity of safety behavior involving often not one, but repeated and endured necessary actions. Influencing single point decision, such as being an organ donor or not (Davidai et al., 2012), can sufficiently be influenced at one strategic point of time. Influencing endured desired behavior (e.g., constantly wearing gas detector) is likely to benefit more from a higher exposure to nudges throughout the day; which also increases the chance of eliciting positive social influence through shared vigilance (Brizon & Wybo, 2006). This in line with the System 1 and 2 reasoning, where System 1 benefits of assisting choice architecture at multiple relevant decision points, because of the lack of capacity of System 2 to keep this safe thought active during the day (Kahneman, 2011).

Interestingly, our findings confirm the previous finding in nudge literature that combined nudge interventions have a bigger effect than in those nudges in isolation (Ayal et al., 2021; Brandon et al., 2019). This additivity of our safety nudges is promising to counter the criticism on the smaller effects of nudges. If small, but cost-efficient, nudge effects can be combined for bigger impact, its relevance for safety management increases. This combination of nudges, either implemented simultaneously or in sequential fashion, holds the potential to foster a safety culture by making increased safety compliance more visible to other colleagues (e.g., altering perceived social norms, Bicchieri (2017)). In addition, making safety more visible and present through nudges could elicit the idea that managers put more effort into safety (DeJoy, 2005). This perception in turn might lead to reciprocal tendencies of workers (Molm et al., 2007), making them more willing to comply to safety guidelines (Walker & Hutton, 2006) and potentially more receptive to safety nudges. An important determining factor for nudges to support a change in safety culture is the long term effect of those nudges. Our study finds some support of the persisting effects on the medium-long term (i.e., 3 months) for the hand shaped reminders. The long term effect of other safety nudges stills needs to be explored. This need holds not only for safety nudges, but for nudge literature in general, which only provided limited results on lasting impact, underscoring the difference between specific types of nudges and the role of implementation context (Brandon et al., 2017; Marchiori et al., 2017; Van Rookhuijzen et al., 2021).

12.2. *A new psychological framework for addressing industrial safety behavior*

The fact that nudge applications exist in industrial safety practice and research, but have not been addressed as such, shows the lag of adopting the practice of nudging and dual-process theories of decision-making in this field. The benefit of this adoption would be to structure nudge development and to categorize existing interventions that enhances both communication of successful approaches and facilitates further improvement. By using this new psychological framework, more psychological depth can be provided in the evaluation of the human factors contributing to safety (Shappell & Wiegmann, 2001). This can explain, and predict, workers experiencing high levels of fatigue or cognitive load (e.g., due to complex tasks or taxing working conditions) (Aldekhyl et al., 2018; Tinghög et al., 2016) to be less susceptible for System 2 interventions (e.g., safety campaigns, work instructions or training); for example due to memory lapses. Good choice architecture can help to structure workplaces (i.e., both physical and digital) that appeal to System 1 functioning, which keeps operational even during taxing work conditions (e.g., unexpected production problem, night shifts, extreme temperatures and environmental noise, etc.). The taxonomy proposed by Münscher et al. (2016) facilitates nudge development, relevant to the psychological barriers at play. The three clusters of nudge interventions defined provide a good starting point to develop industrial safety nudges and are likely to evolve along with the nudge literature. The new psychological framework discussed should not replace existing safety models, including those on safety culture (DeJoy, 2005; Vierendeels et al., 2018) or human factors (cfr., Reason's Swiss Cheese Model or HFCAS), but should be treated as a complement that provides greater psychological depth.

Together with the new psychological framework of bounded rationality, and the associated practice of nudging, goes a necessary endeavor to rethink the ethical framework in which behavior change initiatives operate (Bowman, 2018). The FORGOOD framework can be used as a guideline to steer and evaluate the ethical application of nudges (Lades & Delaney, 2022), for both practitioners and ethical boards, but scholars agree that more rigorous monitoring practices (e.g., behavioral audits) and regulations are needed to control for unintended side effects of interventions or malicious attempts for manipulation (Chowdhurry, 2021; Mills, 2023). In addition, advancing machine learning technologies have made the proliferation of risk (e.g., misinformation campaigns) and the need for ethical protocols and risk mitigating actions more pressing (Mills et al., 2023).

12.3. *Nudging as part of a holistic safety approach*

The findings of the two field experiments show the potential of the nudge approach for industrial safety. The assessment of long term effects and their scalability will need to enforce this statement in the near future (Lindhout & Reniers, 2017; Marchiori et al., 2017). This leads us to the question how nudge intervention can be integrated in a holistic safety approach that incorporates human, technical and organizational elements.

Both Reasons' Swiss Cheese model (Reason, 1990) and the HFCAS model (Shappell & Wiegmann, 2001) highlight the multiple layers that contribute to unsafe behaviors, including organizational influences, (in) consistent supervision, preconditions for unsafe acts and unsafe acts themselves (discriminating between violations and errors). Taking the perspective of those models the concept of 'layered nudging' can be introduced. Layered nudging captures the capability of nudge interventions to be implemented on multiple levels, being it vertical or horizontally. Vertical layered nudges are implemented at multiple levels in the (organizational) hierarchy, to prevent fallacies in decision-making processes that can contribute to safety accidents. This can be seen as an optimization of multiple lines of defense, that prevent accidents to 'slip through the holes' of the Swiss Cheese metaphor. Horizontal layered nudging follows the same reasoning of lines of defense optimization, but focuses on multiple subsequent decision points that lead to a certain undesired action for a specific group or individual on the same hierarchical layer (e.g., relevant to gas detector compliance are picking up the detector, calibrate it, put it on correctly, etc.). Although the distinction between vertical and horizontal layered nudging can at times be useful, the main idea is that nudges can contribute to influence desired behavior by working on multiple levels (i.e., lines of defense), by optimizing managerial decision-making as well as influencing workers' unsafe behavior more directly.

Hallsworth (2023) proposes to use boundedly rational behavioral insights as a 'lens' to see human behavior and efforts to change it. By this, he means that technical improvements or alteration in the workplace, for example, should take into consideration their impact on the human element. Better-designed safety PPE's stored at a more inconvenient place could even be worse than the older models that were easily accessible because of a lower level of compliance. Those conflicts can arise from taking a more rational perspective, instead of this 'behavioral lens'. Hallsworth (2023) uses the term 'choice infrastructure' capturing the need of sufficient capability (and support) to use this behavioral lens from the very start, such as designing a new work place, instead of trying to overcome existing problems by adding choice architectural interventions (i.e., nudges) when the new workplace appears to be misaligned with human behavior.

12.4. Limitations and further research

Methodological limitations of this study include having no separate control group in experiment 1, no consistent removal and re-entry of nudges to isolate the effect (e.g., ABAB), and similar nudges not being tested at multiple locations. Most of these limitations are due to limited resources and unforeseen practical challenges, common to field experiments (Samek, 2019), which on the other hand have the advantage of high ecological validity. They highlight the need to complement field studies with more controlled and affordable experiments (e.g., online or lab) and follow-up studies. Those follow-up studies should a) aim to replicate findings, b) zoom in on a specific nudges by testing a range slightly differing applications and c) test the same nudge at multiple locations (i.e., assessing both contextual moderators and scalability). Another way to meet these requirements is via collaborative action. Massive field experiments or 'mega studies' have been proposed as a novel and promising method to overcome common limitations in applied behavioral science (Milkman et al., 2021; Ruggeri et al., 2020). By collecting millions of data from multiple independent teams, these studies allow to test dozens of nudge variations in various contexts, and would enable a thorough assessment and optimization of future industrial safety nudges. These mega studies could equally provide more insights in how work place conditions (i.e., individuals as employees, situational factors and cultural variations; Kubera (2023)) influence nudges differently than applications in public and private situations, by comparing the same nudges in those different settings.

Nudge effects often cumulate (Ayal et al., 2021; Brandon et al., 2019). Further research should explore why additivity of nudge effects seem apparent. Do combined nudges work on different psychological processes that add up, or is it just an increase of intensity of the same processes? Also, different types of nudges elements might influence certain individuals differently, as acknowledged by scholars who stress the need of for heterogeneity approach of nudging (Bryan et al., 2021; Hallsworth, 2023; Sunstein, 2022). This aligns with previous work highlighting the need to consider personality traits (i.e., agreeableness, conscientiousness, neuroticism) as key correlates of workplace safety (Beus et al., 2015). Future work should explore potential interactions between nudges and these personality traits to inform personalized behavior change interventions.

To evaluate industrial safety nudges effectively, a systematic analysis synthesizing relevant pre-existing safety interventions that qualify as nudges is crucial (Lindhout & Reniers, 2017). Münscher et al.'s (2016) nudge taxonomy provides a useful framework for this analysis, but continuous updates are necessary to accommodate ever new and harder to classify behavioral techniques (e.g., priming).

Some findings in this study show persistent medium-term effects of industrial safety nudges, but more research is needed to see if the effects endure for a longer period. Next to long-term durability, understanding contextual conditions that moderate or mediate safety nudges is equally essential, and aligns with the broader challenges the nudging approach faces today (Hallsworth, 2023). Consistently, exploring interactions between safety nudges and traditional interventions like informational campaigns and training (cfr., System 2) is a vital yet unexplored research direction. Positive findings regarding these interaction effects could validate the role of nudges in enhancing industrial safety management alongside more established interventions.

13. Conclusion

This study demonstrates that nudge interventions can be a promising approach to promote safety behavior in the process industry, particularly in the steel industry. The findings from the field experiments show that nudges, such as icons and hand print cues, were effective in increasing safety compliance among workers. This suggests that nudging can be a cost-effective solution to promote safety behavior and prevent severe accidents in the workplace. While nudging has been widely applied in different domains (including finance, health, traffic safety and sustainability), its relevance for safety in the process industry has not been systematically investigated. This study fills this gap by providing empirical evidence of the effectiveness of nudges in the steel industry. The organizational implications of a safety nudging approach are also discussed, highlighting the importance of integrating nudging into a holistic safety approach. In essence, the results of this study have important implications for the steel industry and other process industries, as they demonstrate the potential of nudging to improve safety behavior and prevent accidents. Further research could investigate the generalizability of these findings to other industries and explore the long term effects of nudging interventions on safety behavior. Nonetheless, the present study provides a valuable contribution to the literature on safety interventions, emphasizing the importance of implementing a multi-faceted safety approach that includes nudging.

Funding and conflicts of interest

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The position of all researchers at independent academic institutions minimizes the conflict of interest. The funding source had limited to no involvement in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

Ethics approval

APA ethical standards were followed in the conduct of the study and ethical approval was received from the ethical board of the Flemish Government and ArcelorMittal Belgium.

Consent to participate and for publication

Consent to participate and publish was obtained from all participants included in the study, directly (written or verbal) and indirectly (through labor unions).

Availability of data and material

On demand of the ethical committee, the data of the study are not available and cannot be shared public, due to privacy regulations for the employees and organization involved. Data are available for researchers who meet the criteria for access to confidential data upon request.

CRediT authorship contribution statement

Samuël Costa: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Wouter Duyck:** Writing – review & editing, Supervision, Methodology, Funding acquisition. **Eline Van Wouwe:** Investigation, Formal analysis. **Nicolas Dirix:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

See Table A1, Table A2.

Table A1
Structured observation form for tallying CO detector compliance (blank version and translated from Dutch).

Date:	**IMPORTANT**:
Department: Blast furnace and sinter plant	o Only **workers**, no administrative employees passing by. o We do **not look if CO detectors are calibrated**.
Observed team:	o Reason: this requires addressing the workers, which can negatively affect the results of the research. o If workers are not okay or only partially okay, please **do not respond to them temporarily** (unless extremely necessary). This is detrimental to the study. We are looking at the effect of nudges on safety behavior. Not the effect of getting comments on safety behavior. o Please **tally** the numbers and enter this later in **Excel.**
Number of tallied workers in **total**	
How many workers:	
Wear a CO-detector	
Activated the CO detector	
Wear a CO-detector in the **right place** (activated or not) (right place = on the chest - uncovered)	
Wear a CO-detector in the **wrong place** (activated or not)	Beneath jacket On pants Somewhere else (specify where)
Are **completely compliant** (CO-detector activated + right place)	

Table A2
The amount of pushes on the green and red buttons (Experiment 1).

Time	Green button	Red button
Day 1	198	95
Day 2	140	51
Day 3	115	40
Day 4	80	16
Day 5	120	28
Day 6	95	35
Day 7	151	27
Day 8	125	32
Day 9	109	28
Day 10	85	32
Day 11	120	20
Day 12	110	24
Day 13	123	49
Day 14	135	18
Day 15	82	30
Day 16	102	13
Day 17	130	25
Day 18	88	26
Day 19	125	35
Day 20	121	19
Day 21	101	35
	2455	**678**

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