Cognition-Informed Safeguards: Lessons and Recommendations for Safeguards Practitioners from Cognitive Science Research

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Abstract:

Despite significant advances in measurement and detection equipment and information analysis methods for international nuclear safeguards, all safeguards verification activities are inherently limited by a common factor: humans. Developments in safeguards equipment and methods are critically important, but so are the care and maintenance of those safeguards practitioners who are expected to use them. The domains of cognitive science and cognitive psychology offer rich information on human performance and cognition. In this article, we summarize key points relevant for international safeguards from extensive literature in the cognitive science sub-domains of attention, cognitive biases, cognitive off-loading and knowledge transfer, the prevalence effect, sleep, stress, task switching and multi-tasking, visual search and visual inspection, wayfinding, and multilingualism. We provide actionable recommendations in a safeguards-relevant context.

Keywords: *cognitive safeguards, international safeguards*

1. Introduction

The verification of international nuclear safeguards is an inherently human activity, combining observations and data collected and analyzed by human inspectors, analysts, technicians, and clerks to meet a series of technical objectives. Dialogue surrounding international safeguards challenges focuses on the rising workload of inspectors and analysts due to new facilities, changing facility types, new data sources, and stagnant budgets; however, even humans in ideal working conditions face the disparaging reality that people make mistakes. By using principals of cognitive science combined with an understanding of safeguards verification tasks and work environments, we can make recommendations to safeguards practitioners that can potentially enhance their performance in this high-impact field.

Some aspects of the international safeguards verification workflow are highly nuanced and unique to the safeguards domain; for example, escorted navigation of complex industrial environments. However, other activities are more common across multiple domains and can benefit from the existing corpus of cognitive science research without significant modification. This article is intended to share lessons and implications from a plethora of peer-reviewed cognitive science literature with international nuclear safeguards practitioners. Most of this literature is not focused specifically on safeguards experiments, but on relevant and closely related activities from which recommendations can be applied to international safeguards activities. Some research has been published by members of our research team focusing explicitly on nuanced safeguards-relevant tasks.

In this article we summarize literature from the cognitive science domain and apply lessons from other fields directly related to safeguards verification tasks to develop cognition-informed safeguards recommendations. The recommendations herein apply to a broad array of safeguards planning and verification activities. The recommendations have also been published as a stand-alone booklet.

2. Attention, Inattentional Blindness and Attentional Misdirection: How Our Minds Focus on What is Relevant

Attention refers to the “means by which we actively process a limited amount of information from the enormous amount of information available through our senses, our stored memories, and our other cognitive processes” [1]. Attention, and what captures our attention, is a significant area of research within the cognitive science domain. Kahneman [2] describes attention as the internal mechanisms that determine or select the significance of stimuli, as well as the degree of that selection. According to Sternberg [1], the three primary types of conscious attention are 1) signal detection, in which one must detect a particular stimulus; 2) selective attention, in which one must choose to attend to some stimuli while ignoring others; and 3) divided attention, in which one allocates their attention to complete more than one task at a time.

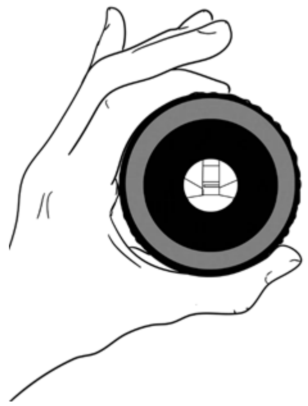

Figure 1: Attention is an internal mechanism that determines the significance and degree of stimuli from the vast amount of information available through our senses. Two mechanisms in which attention fails to capture a relevant event include inattentional blindness and attentional misdirection.

There are two related but unique instances in which our attention fails to capture a relevant event: inattentional blindness and attentional misdirection. *Inattentional blindness* is a phenomenon in which “unexpected objects fail to capture attention” [3]. Inattentional blindness, for example, occurs when someone is paying such close attention to a task that they miss something “in plain sight.” One of the most popular illustrations of this was an experiment by Chabris and Simons [4] in which participants were asked to count how many times balls were bounced by individuals wearing white t-shirts in a recorded video. When a woman in a gorilla costume dances through the scene in the middle of the video, about half of the participants miss seeing her the first time. The original video of the experiment is located here: https://www.youtube.com/watch?v=vJG698U2Mvo (accessed June 11, 2020).

Attentional misdirection is defined as the “deliberate diversion of attention away from a visually salient stimulus” [5]. In both inattentional blindness and attentional misdirection, one’s attention is directed towards a certain object or activity, but misdirection is done deliberately with the intention of preventing a person from noticing something. Attentional misdirection has been most studied in the context of illusions and magic tricks [6]. There is debate within the cognitive science community about whether attentional misdirection from a third party is distinct from inattentional blindness, but both phenomena offer a situation in which one’s attention is focused on a single event or activity causing them to “miss” pertinent information.

Attention is crucial for inspectors working in the field, as they need to be aware of their environment while conducting safeguards activities. Attention is important for maintaining personal safety, correctly completing inspection tasks, and noting any unusual activities. Attention is also critical for analysts and technicians working at the International Atomic Energy Agency (IAEA) Headquarters. Strict attention is necessary for performing detailed analyses, laboratory procedures, maintenance and calibration on sensitive equipment, and other activities.

Inattentional blindness and attentional misdirection can adversely impact safeguards practitioners—especially those working in the field. The close attention necessary for a copious task—like checking many seal identification numbers—is beneficial for good performance but could cause inattentional blindness to an abnormal reconfiguration of equipment in that area. Social cues or gestures by facility operators or regulators can lead to attentional misdirection, causing inspectors to miss potential indications of undeclared nuclear activities.

Recommendations following our review of the attention literature are below.

Allocate Team Roles: An experimental study conducted by part of our research team at Sandia National Laboratories evaluated inattentional blindness in an international safeguards scenario in which participants compared simulated electronic inventory lists to facility documentation [7]. In this digital list comparison activity, participants checked items off one list as they found them in the second list. During the experiment, the background color of the digital screen changed. Participants were asked to announce when they noticed the changes during the scenario, and recount at the end how many times they observed the color changes. The results of the experiment confirmed findings from Chabris & Simons [4] that only about 40-60 percent of the population will notice a change to the environment during an intense concentration activity. We recommend teamwork allowing one person to be intensely focused on a safeguards verification task, while a second person provides support, engages with the operator or escort, and observes the environment.

Notice Opportunities for Distraction and Misdirection: Inspectors working in the field should be aware of opportunities for distraction and misdirection. In studies of participant response to magic tricks, researchers found that repeated exposure (i.e., more than 10 trials), and especially repeated exposure with feedback on performance, increased a person’s ability to discern a real event (in this study, a coin toss) from a simulated event in a magic trick [8]. We recommend that safeguards inspectors be exposed to multiple trainings in deceptive environments, such as the Complementary Access trainings, to support in-field recognition of potential misdirection scenarios.

Use Checklists for Important Tasks: Since attention may be diverted to stimuli other than the task at hand, Gawande [9] recommends the development and use of simple checklists to ensure critical tasks are being completed according to the required protocols. While Gawande developed his checklists for the medical community, similar definitions of key steps and procedures to avoid missing an important activity or analysis step can support more effective safeguards verification results. We recommend that checklists be developed for several safeguards tasks, both in-field and headquarters based. Example of safeguards checklists might include a checklist of sources to search for an open source analysis, or steps to complete in physical inventory verification for a nuclear power reactor.

Use Visual Aids. One study found that when presenting new information, visual aids support better retention of the information [10]. For State Evaluation Groups (SEGs), positive progress has already been made in the domain of incorporating visual information, such as in environmental sampling results visualization [11] and visual representation of nuclear materials flow through a state [12]. We recommend vetting or peer-reviewing visual information to ensure that the initial reaction to the visual data leads to a correct interpretation of visual presentations.

3. Cognitive Biases: Unconscious Predeterminations that Impact Assessments and Decision-Making

Cognitive biases are “cognitions or mental behaviours that prejudice decision quality” due to their “deviations from reality” [13]. These biases—or unconscious shortcuts—have been examined and catalogued in several ways, one of the most interesting being the Cognitive Bias Codex in which the author classifies cognitive biases by four scenarios in which they arise: too much information, not enough meaning, need to act fast, and not knowing what one should remember [14].

Numerous papers describe the cognitive biases that influence decision-making [15, 16, 17]. Examples of a cognitive bias include:

- The availability heuristic, in which the ease of information retrieval (i.e., examples one can easily bring to mind) increases one’s perception of the global frequency of an event [18].
- Confirmation bias, which is the tendency to overvalue information that supports an existing belief [14].

Figure 2: Cognitive biases are unconscious shortcuts in decision-making that occur when the human brain has too much information to process, insufficient meaning or context, or does not know what to remember.

Cognitive biases, and how they impact decisions and actions, are especially relevant to safeguards during in-field inspections, interpretations of deviations from state declarations, analysis of open source data, and the integration of multiple sources and types of safeguards-relevant information. Cognitive biases can also impact group scenarios such as SEGs, in which individuals and groups make assessments and judgements about safeguards verification in a state. Gazze, Wilson, Mathews, Reyes, & Schanfein [19] explored many cognitive biases as they specifically relate to SEGs, and recommended three phases of action to counter biases that included specific recommendations for training, peer review, mentoring, and quality assurance.

Our recommendations for managing cognitive biases are listed below.

- Use Structured Analytical Techniques. Some authors suggest the use of structured analytical techniques to counter potential biases [19][21]. There are many different structured analytical techniques, each suitable for different types of analysis or questions. Examples of structured analytical techniques include key assumptions check and analysis of competing hypotheses. Though there has been little experimental research into the impact of using structured analytical techniques, research reviewing a selection of U.S. intelligence documents found the reports that described using these techniques “addressed a broader range of potential outcomes and implications than did other analyses” [22]. We recommend that members of SEGs evaluate which structural analytical techniques are most suitable for their analyses and integrate them into the state evaluation processes.
- Engage a Facilitator to Support Equitable Information Sharing. One study found that, in groups, extroverted individuals may be interpreted as being expert in areas beyond their expertise [23]. Another group of researchers recommended paying special attention to differing viewpoints as part of an overall strategy to combat cognitive bias [24]. We hypothesize that active participation in SEGs may be lower for new staff or staff working at lower levels of fluency in English, potentially compounding cognitive biases. We recommend that an IAEA staff member not associated with the SEGs but familiar with facilitation should mediate SEG discussions of important issues or key analysis. Mediation would ensure that all staff are given an opportunity to participate, and that the group uses techniques to avoid groupthink.

4. Cognitive Off-Loading and Knowledge Transfer: Taking Notes to Remember Information and Share it with Others

Cognitive off-loading is “the act of reducing the mental processing requirements of a task through actions like writing down information or storing information in a cell phone or computer” [25]. Notetaking is one form of cognitive off-loading for short-term tasks, but it can also be used for longer term memory and knowledge transfer. Some research indicates that beyond just providing a written record for reference, the act of writing notes by hand can improve higher-level comprehension in the short-term and mitigate the forgetting of information over time [26].

Knowledge transfer refers to the handover of insights (know-what) and experiences (know-how) between individuals or teams [27]. The term knowledge transfer can be used to refer to transferring institutional knowledge or to transferring task-specific knowledge. In this work, we consider only task-specific knowledge transfer. Knowledge transfer has been studied in the psychology community especially within shift workers such as medical providers or power plant operators. Bosua and Venkitachalam [27] found that, due to incomplete or inefficient knowledge transfer methods, "incoming workers tend to solve problems with inadequate information, have an incomplete understanding of significant events that occurred in prior shifts, while workers often attempt to solve the same problems across different shifts."

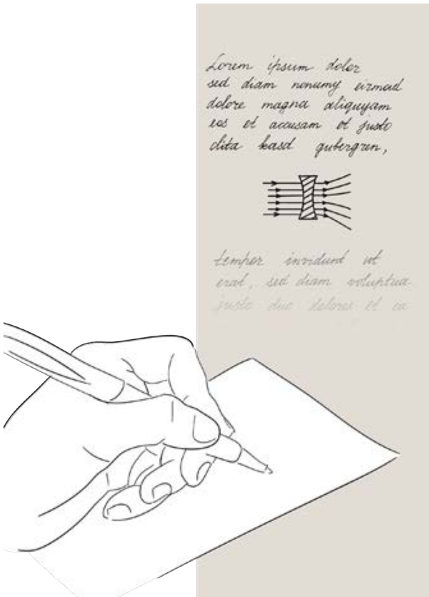

Figure 3: Cognitive off-loading is the act of reducing mental processes through actions like notetaking. Knowledge transfer is the transfer of information—specifically insights and experiences—between individuals or teams.

Notetaking has relevance for many safeguards activities, most notably for on-site inspections. Notetaking can be used to record observations and task status, record personnel information, make illustrations of key pieces of equipment, etc. For headquarters-based activities, notetaking can be used in SEGs to record the analytical findings and interpretations of each SEG member. Notetaking can also be used by individual inspectors or analysts as they complete their activities that will later support SEG activities.

Knowledge transfer is critical as inspection teams may differ between visits to a site. While knowledge transfer is traditionally studied for round-the-clock personnel handoffs, international safeguards inspectors face an additional challenge of the time gap between when they complete their activities and when the next set of inspectors will begin preparing for theirs—which could be weeks or months apart.

Our recommendations for notetaking and knowledge transfer are below.

Recommend Times for Taking Notes. One study on notetaking used a computer-based task in which participants arranged circles on a screen according to visual instructions or patterns provided within the experiment. Some participants were instructed to place visual reminders for themselves at certain points in the task to remind themselves of circle placement, while others could set reminders spontaneously. The researchers found that self-perception of memory capability influences when participants set reminders, with individuals who believe they have high memory capability setting fewer reminders than others. The study found that setting the visual reminders improved performance for all participants regardless of self-perceived memory capacity [28]. For safeguards, we recommend that reminders be set for inspectors or analysts to take notes as checkpoints throughout their activities, such as at natural stopping points during breaks or between tasks.

Define a Structure. In the cognitive science literature, "boundary objects" refer to physical or electronic representations that can be used to transfer knowledge between individuals or organizations. Research in the educational psychology field found that when people are provided with boundary objects such as outlines in advance of an activity, they can use those outlines to support more organized notetaking and demonstrate improved memory [29]. Even if an outline or notes structure cannot be in-hand during an inspection, having the structure in mind while in the field could support better notetaking. This recommendation supports current practices for the IAEA's use of structured forms such as inspection reports.

Take Multimodal Notes. In a study on the impacts of drawing on notetaking [30], researchers found that drawing an item provided support for recalling that item later relative to writing text alone, across multiple settings, instructions, and encoding strategies. The researchers propose that the positive impact on recall of drawing over writing may be due to the integration of multiple types of memory involved in recalling an object from drawing. A similar impact of drawing was shown in an experiment conducted by members of this research team, designed to simulate a safeguards scenario. We found that notetaking improved memory of complex visual arrays relative to memory for items studies without a notetaking aid. Notes that included both text and drawings/illustrations were most useful—both to the individuals who took the notes and to other people who were given the notes to use to complete a change-detection task without having seen the initial array [31].

Use Cameras When Available, But Not Exclusively. In the same study, we found that the use of digital cameras increased accuracy on some change detection tasks relative to handwritten notes only, especially for subtle changes. Using a camera saved time compared to taking handwritten notes, but using cameras at the time of test took longer than referring to handwritten notes. Further, the use of digital cameras made participants more confident in their findings even when the participant's conclusions from those photographs were wrong, whereas participants with handwritten notes were less confident when they were wrong [31]. Digital cameras are recommended when available, but should always be accompanied with written notes or other sources of information.

Review Inspection Notes. The educational psychology community has repeatedly examined two distinct functions of notetaking—storage and encoding. The *storage function* "suggests that the review of notes stored in written form facilitates retention" by helping students consolidate noted information, stave off the natural forgetting process, or re-learn information that was already forgotten [32]. The *encoding function* "suggests that the process of recording notes facilitates learning even in the absence of review" [32]. In other words, the process of writing the information down increases one's ability to recall it later. For safeguards, both of these functions can support inspection activities. For storage, notes can be shared with others or used to support documentation during a knowledge transfer process. For encoding, inspectors who write down the information and then re-visit the same location will be more likely to remember their notes. Kiewra [32] describes several studies that show the benefit of reviewing notes. In one study, participants who did not attend a lecture but reviewed borrowed notes performed better on an exam than those who attended lecture but didn't review their own notes. We recommend reviewing one's own notes at the conclusion of an inspection activity and any notes that are available in preparation for a new inspection.

Define Hand-off Procedures. In a series of case studies on knowledge transfer in various industries—including manufacturing, information technology, and heavy industry—researchers found that having a defined procedure for preparing for and conducting shift handover activities facilitated effective knowledge transfer [27]. Practices that appeared to have positive impact included periodic mandatory training to review the procedures with staff, and management-defined information to be recorded for handover, including how to document unusual events and the method for doing so (e.g., fill out a form and give it to a single point of contact). This practice required effective infrastructure such as common access via computer systems to all so that staff who needed access could get the required information. For safeguards, the recommendations from this study imply that the IAEA should continue using standardized inspection reporting forms that can be accessed by those with appropriate roles.

Record Inspection Briefings. One study on hand-off strategies from high-consequence failure industries—including ambulance dispatching, railroad, nuclear power, and space shuttle mission control—identified 21 strategies for hand-off of information [33]. One of the most relevant strategies for safeguards recommended was that hand-offs be completed in person and audio recorded for later reference. We recommend that inspection reports presented to management or SEGs be recorded and then used for reference by inspectors preparing for their next visit.

5. Prevalence Effects: Searching for Rare Events or Objects

The prevalence effect refers to the phenomenon in which observers are more likely to miss a rare target (i.e., the thing that is being searched for) than frequent targets [34]. The prevalence effect has important impacts on many visual search activities, such as airport security screenings. The prevalence effect can occur in different manifestations dependent upon the type of task being conducted, and can result in ending the search prematurely, missing a target due to a rare configuration, or missing a target due a premature reflexive response.

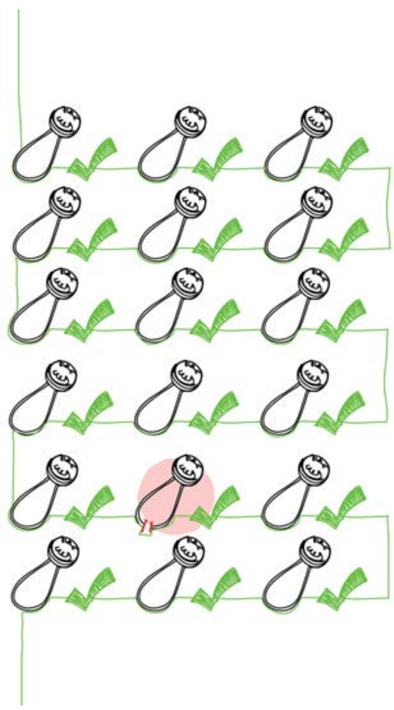

Figure 4: Prevalence effect is the phenomenon in which one is more likely to miss a target that occurs with low prevalence (i.e., low frequency) than targets that occur with higher frequency.

There are many examples within international safeguards in which an inspector or analyst is looking for low prevalence phenomena. A few examples include:

- In verifying containment of equipment or cabinets, or the integrity of seals, very few will have evidence of tamper.
- In reviewing scientific and technical publications, few publications will indicate undeclared research relevant to the nuclear fuel cycle.
- In complementary access visits, few locations will have evidence of undeclared nuclear activities.

Based on the cognitive science literature, our recommendations regarding the prevalence effect for safeguards are below.

Train with Periods of Increased Prevalence. Wolfe and colleagues [35] found that inserting short periods of high prevalence targets can help mitigate the prevalence effect. While this would be impossible to do in natural environments such as inspections or open source information collections, it could be attained by sending inspectors or analysts to trainings in which they experience high prevalence with feedback. There remain several uncertainties regarding the duration of the effectiveness of these trainings, or how training environments can generalize to real-world safeguards activities. We recommend adopting several training methods on a trial basis for safeguards and monitoring both participant feedback and any differences in safeguards outcomes.

Prepare for Field Activities with Brief Periods of High Prevalence. Wolfe, Brunelli, Rubinstein, & Horowitz [36] suggest that "a regimen of a brief high-prevalence block just prior to going to work…might be worth investigating as a countermeasure to the prevalence effect." We further suggest that while realistic high prevalence effects are difficult to simulate for safeguards, a game, mobile application, or virtual or augmented reality in which inspectors encounter high prevalence of a safeguards-interesting theme completed just prior to a safeguards verification activity could counter prevalence effect. For example, inspectors could complete a safeguards-relevant game in which they confirm seal inventory with a high rate of tampered seals, incorrect seal numbers, or missing seals.

6. Sleep Deprivation: How to Get Good, Effective Sleep at Home and Away

Sleep is important to cognitive functions including memory consolidation [37] and attention [38]. Further, *sleep deprivation*—not getting sufficient sleep—can significantly affect functioning, including cognitive and motor performance, as well as mood [39]. According to the Sleep Foundation guidelines, most healthy adults need seven to nine hours of sleep, while older adults need seven to eight hours of sleep per night [40]. However, sleep is often disrupted, especially due to travel across time zones (jet lag) or sleeping in unfamiliar environments such as hotels.

Figure 5: Sleep impacts many cognitive functions, such as memory consolidation and attention. Disrupted sleep can negatively affect cognitive and motor performance, and mood.

Safeguards inspectors and technicians who frequently travel for on-site activities in nuclear facilities are likely to experience disrupted sleep due to time changes and sleeping in unfamiliar places. While our findings will focus on those travel-related sleep disruptions, recommendations for sleep hygiene apply to all people who want an effective and restful sleep.

Our safeguards-specific recommendations for getting good sleep and recovering from disrupted sleep from the cognitive science literature are below.

Provide Time for Sleep Recovery. The sleep research community documents what it calls the *first night effect*, in which the first night of sleep in an unfamiliar environment is disturbed [41]. The sleep disruptions from the first night effect are similar to insomnia. Sleep researchers have observed that the disturbed first night of sleep in a new environment (usually due to participation in a sleep study) can result in poorer memory consolidation [42] and attention [43]. Others found that after a night of sleep deprivation, returning to normal took one to two nights of normal sleep depending on the type of cognitive task studied [44]. This is consistent with findings presented in Alhola and Polo-Kantola [43] that one night of additional rest supported recovery of cognitive function. We recommend grouping closely geolocated inspections together, so that an inspector stays longer in a single time zone. This may help mitigate the detrimental effects of jet lag and first night effects.

Practice Good Sleep Hygiene. In general, sleep researchers recommend good sleep hygiene. These are activities or preparations that promote good sleep and daytime alertness. According to the National Sleep Foundation, good sleep hygiene practices include: limiting daytime naps to 30 minutes; avoiding stimulants such as caffeine and nicotine close to bedtime; using alcohol only in moderation; exercising regularly (but not too close to bedtime); avoiding food or drinks that may trigger indigestion; ensuring adequate exposure to natural light; establishing a regular, relaxing bedtime routine; and making sure that the sleep environment is pleasant including comfortable mattress and pillows, cool temperatures, low to no light, and white noise machines or other relaxing sounds [45]. Other sleep studies recommended avoiding cognitive arousal in bed, such as worrying, planning, or thinking about important things; not engaging in exciting or emotionally upsetting activities before sleep; and avoiding excessively noisy environments for sleeping [46].

Track Sleep to Identify Poor Sleep or Sleep Deprivation. Alhola and Polo-Kantola [43] suggest keeping a sleep diary to track sleep in order to better help identify when a recovery period is needed. We also recommend tracking sleep with personal devices such as fitness trackers that can monitor the quality and duration of sleep.

7. Stress: Working Under Pressure

Stress is defined in several ways within the cognition community. Staal and colleagues [47] describe three models of psychological stress, which revolve around an individual's cognitive and behavioral responses to stressors within their environments. Descriptions of stress within the cognitive science community range from temporary exam-related anxiety, to strongly stressful single events like natural disasters, to lingering post-traumatic stress disorder from a period of intense stress, to chronic stress from our daily lives (We are unable to make clinical recommendations for how to deal with intense stress, PTSD, anxiety, or other mental health topics. If you believe you are experiencing stress that is greater than typical day-to-day stress described here, seek out the help of a mental health professional or your doctor.). Across the spectrum of stress, cognition can be impacted by stress "with situations that can range from the mild interference that exposure to brief stressors can induce on the ongoing processing of information to the impact of traumatic experiences on the establishment of enduring and devastating memories" [48].

Yerkes and Dodson [49] were some of the first researchers to describe an early increase in performance as stress increases, with performance reaching an optimal point and then degrading as stress continues to increase. This is referred to as the Yerkes-Dodson performance curve. Sandi [48] found that high levels of stress reduce performance, but that mild-to-moderate levels of stress can support attention and memory. This section focuses on periodic, moderately stressful events such as those encountered in some work environments relevant for international safeguards.

Figure 6: Stress is a psychological and physiological response to stressors in an environment. While some mild, short-term stress can enhance attention and memory, ongoing exposure or brief high levels of stress can hurt performance.

Stress can be part of any professional work environment. International nuclear safeguards practitioners, however, may experience additional stress due to a number of unique factors. For inspectors working in the field, stresses can include difficult negotiations with facility operators or national regulators, working in potentially hazardous environments, or working under time constraints to complete inspection tasks. For analysts or technicians working at IAEA Headquarters, stresses can include having limited time to complete many important tasks, unanticipated short bursts of activity from high-priority tasks that require immediate attention, and interpersonal stresses related to working in an international environment with a high staff turnover rate.

We have adapted recommendations for coping with – and building resilience to – stressful situations for safeguards below.

Focus on a Single Task. Ansari, Derakshan & Richards [50] found that higher anxiety individuals (a personality trait measured through a self-assessment) had lower working memory and less ability to shift cognitive tasks. They found that the more anxious an individual is, the more likely they are to get distracted by environmental stimuli and be unable to accurately or quickly complete their required task. We recommend that during work situations of heightened anxiety, safeguards practitioners focus on a single task or activity they have to complete before preparing for or starting the next activity.

Build Resilience Through Training. Staal, Bolton, Yarough & Bourne [47], whose research focuses on military applications, indicate that experience and expertise build resilience to stress that could otherwise impair performance. They recommend that training under pressure may help reduce "choking or panic during subsequent performance under pressure." We recommend that safeguards training include moderately stressful scenario role-playing about difficult negotiations or time-constrained inspection tasks.

Team with Experienced Peers. Another study tested the performance of higher and lower skilled soccer players who, while viewing five-second segments of soccer games from a first-person perspective, were asked to anticipate the next action of the player in possession of the ball [51]. Those leading the study tried to incite high anxiety among the participants by telling them that their results would be compared to those of other players and evaluated by the coach. The study found that the players responded to anxiety differently according to their level of skill, with the lower-skilled players suffering a larger negative impact on task performance than the higher-skilled players. While soccer moves might not be directly relevant to safeguards, we propose that the ability to predict what will happen increases with experience. We suggest pairing more experienced inspectors with less experienced inspectors in potentially anxiety-inducing scenarios in order to mitigate negative performance impacts.

Express Positive Reinforcement to Reduce Stress. Cognitive scientists frequently study evaluation anxiety, which is defined as “a cognitive and emotional experience that commonly arises in social, academic, clinical and vocational settings” in which the stress of being “tested” impacts people’s ability to perform the tasks that are required [52]. Coy and colleagues describe one explanation for evaluation anxiety and its negative impact on cognitive performance is through Cognitive Interference Theory, which suggests that “negative off-task self-dialogue…interferes with performance by distracting an individual from the task at hand”. In one study, Coy and colleagues proctored exams to groups of students, some of whom received intentionally anxiety-inducing instructions and some of whom received neutral instructions. Those who received the anxiety-inducing instructions reported more negative, off-task self-dialogue after the test, and performed worse on cognitive tests. While safeguards practitioners are not routinely “tested” in this way, and the authors do not examine the impact of positive self-dialogue, we recommend positive self-dialogue before and during potentially stressful situations.

8. Task Switching and Multi-Tasking: Addressing Competing Cognitive Demands on One’s Attention

Task switching and multi-tasking exist on a continuum of divided attention in which attention is allocated across multiple tasks at once. *Multi-tasking* refers to situations in which an individual must split their attention between multiple tasks simultaneously. *Task switching* refers to situations in which individuals switch their attention between the sequential performance of two or more tasks that require at least partially different processing sources [53]. Both multi-tasking and task switching are challenging because they draw upon limited processing resources, and often result in a decrement to performance, either through slower or less accurate task performance.

Figure 7: Task switching is when one alternates their attention between tasks. Multi-tasking is when one divides their attention across tasks simultaneously.

Safeguards inspectors working in the field are often required to task switch and multi-task. During a typical onsite activity, an inspector might be checking inventory lists, verifying seals, paying attention to spatial navigation, maintaining situational awareness, talking to their inspection partner or facility operator, and handling equipment. Safeguards analysts working at headquarters are more likely to face task-switching effects between analytical tasks, between tasks and email, and being interrupted.

We have tailored recommendations from the cognitive science literature on task switching and multi-taking for safeguards below.

Support Single-Tasking for Analytical Tasks. Decades of work in cognitive psychology have found both dual-task costs as well as switch costs, in which task performance is lower when people try to simultaneously perform two tasks or switch between two different tasks, respectively [54]. We suggest the promotion of single-tasking within the institutional culture for headquarters-based safeguards activities. For example, we suggest scheduling “focus time” in which there are several hours of uninterrupted work time during the day.

Use Breaks to Switch Tasks. While task switching is generally described as being detrimental to task performance, there are some instances in which switching tasks has been shown to have some benefits to performance. For example, even a brief break during a vigilance task can boost performance [55]. By working only on a single, high-concentration task for 30 minutes and then intentionally switching tasks, task switching can serve as a mental break from cognitively demanding concentration activities. We recommend intense focus on single tasks to the extent possible for durations up to 30 minutes, followed by a brief break or switching to a task that requires different cognitive functions. If an inspection partner is present, switching roles with that partner can also be used as a cognitive break.

When Multi-Tasking is Required, Choose Non-Overlapping Cognitive Tasks. Research on distracted driving suggests that distractions from cellphone communications—both on a device and hands-free—are harmful to task performance [56]. Similar outcomes have been found in the wayfinding literature, in which secondary spatial and verbal tasks performed by the participants interfered with the encoding of wayfinding information [57]. However, we are constantly task switching and multi-tasking in our daily lives, for example, when listening to a news broadcast while driving or talking with family while cooking. Given that even seemingly unrelated tasks can interfere with each other, we recommend that when multi-tasking and task switching is necessary, safeguards inspectors find tasks that can divide attention between complementary, rather than competing, cognitive capabilities.

9. Visual Search and Inspection

Visual search is "a scan of the environment for particular features—actively looking for something when you are not sure where it will appear" [1]. Search tasks can include activities such as a *feature search*, when a distinctive feature such as color or size defines the search criteria, or a *conjunction search*, during which a specific combination of features is being searched for together. Visual inspection is a similar but specialized activity. *Visual inspection* is "careful and critical examination, especially for flaws…[and] is typically a deliberate, in-depth exacting process that requires more than mere looking or scanning" [55].

Figure 8: Visual search is a scan of the environment for a target or feature that might not be present. Visual inspection is a more deliberate and careful examination, especially for flaws.

Visual search is important for physical inventory and design information verification activities, as well as checking containment of safeguards equipment, examining seals for evidence of tamper, and satellite imagery analysis.

Our safeguards recommendations for visual search and visual inspection, based on the cognitive science literature, are provided below.

Take Time to Avoid Errors. In an overview of human factors literature relevant to visual inspection, researchers cited studies in which time pressure can result in inspectors being more "lenient" and inadvertently letting borderline cases "pass" an inspection [55]. For safeguards, this could possibly translate to not noticing indications of tamper. One study conducted by members of our research team specifically focus on visual search for a safeguards-like inventory verification task. We found that the presentation of list information affects the speed at which participants can complete a list-matching activity, and that presenting the two lists in a very similar order produced the fastest response times. We also found that presenting lists in this fastest configuration resulted in decreased accuracy in the detection of subtle errors (e.g., a transposition of two digits rather than a missing item or more blatant mismatch). Although presenting information to enable more efficient safeguards inspections may be preferred, we recommend that sufficient time should be allocated for all visual inspection tasks to help prevent avoidable mistakes.

Have Sufficient Lighting for the Task. In a literature review of factors that impact visual inspection accuracy, Megaw [68] points out four factors that impact inspector error—visual acuity, lighting condition, time for inspection, and feedback. Time and feedback are covered elsewhere in this section, and visual acuity should already be considered for this type of activity. The overview of research on lighting indicated that "good lighting is essential in reducing visual fatigue," and that adequate lighting can reduce the difference in visibility for low- and high-contrast items. However, the author also notes that too much lighting could induce glare for some activities. IAEA inspectors should ask for appropriate task lighting for their activity, which might mean turning the lights down for some activities. Headquarters-based staff should also ensure that they have sufficient task lighting, for example when analyzing satellite imagery or inspecting seals returned from the field.

Provide Feedback. In a study that looked at the impact of performance feedback on visual search tasks in airframe structural inspections, researchers found that providing feedback on search process and strategy resulted in more improvements to the task performance (measured in time and accuracy) than only providing feedback on the accuracy of the search [69]. Feedback in graphical or visual forms (including visual representations of the participants' search patterns) provided a positive effect on users' performance. While the research focused on an extended visual search task over the entire fuselage of an airplane, we posit that similar feedback on process or strategy could benefit smaller visual search tasks relevant to international safeguards. We recommend that performance feedback be provided to inspectors and analyst by their peers, and that the feedback include comments on accuracy and strategy or method.

Define a Search Strategy. Using a defined search strategy—such as a snake patterns from side to side, top to bottom—has been shown to improve inspection performance in visual inspection tasks over a random search pattern [70, 71]. We recommend that safeguards inspectors and analysts be trained in specific search patterns in order to be more effective when examining for indications of tamper, searching for items within overhead images, and conducting other safeguards visual searches.

Take Breaks or Switch Tasks Often. In an overview of human factors research on visual inspection, See [55] recommended limiting visual inspection activities to 30 minutes at a time based on anticipated fatigue for this type of task. The authors recommended working in short segments of time, and then either switching tasks or taking a break from inspection for 15 minutes after each 30-minute inspection period. Because safeguards inspectors are time-limited and not able to easily take breaks due to the protective clothing and radiation screening required in many facilities, we recommend switching tasks or roles (e.g., equipment user and recorder) every 30 minutes for similar effect.

Efficiently Display Lists. In a study that examined how lists of surnames with first initials are presented visually on a screen, researchers found that decreasing the screen density—adding white space or a blank row between items—of an electronic list led to faster search times [72]. For these lists, they added more space by suppressing redundant information (in this case repeated surnames) rather than repeating them for each entry along a vertical column. Matzen and colleagues [7] also found that arranging lists in numerical order supported more efficient list searches. We recommend adopting efficient list organization practices for IAEA-controlled information. If an inspector will be searching IAEA-controlled lists (seals inventory lists, for example) or a physical inventory list provided prior to an inspection activity, the list should be appropriate spaced and arranged in alphanumeric order. Repetitive text such as the first portion of ID numbers could be partially truncated to make the lists easier to scan.

10. Wayfinding: Using Sense of Direction and Navigational Aids

Wayfinding refers to how people understand and locate themselves in physical space. It can include navigation (finding the way between desired locations), route knowledge (familiarity with where one has already been), landmark knowledge (locations of points of interest), and site or survey knowledge (an overall conception of the layout of a physical location or area).

Figure 9: Wayfinding is an understanding and ability to locate one's self in physical space, and includes finding the way between desired locations, familiarity with the route one has taken, knowledge of locations of interest, and an overall conception of the layout of an area.

Wayfinding plays an important role in onsite safeguards verification activities. Safeguards inspectors must often navigate through unfamiliar geographic areas to locate nuclear facilities, before being escorted through typically complex industrial spaces. Safeguards inspectors need to know their exact location within a facility, the route they took within the facility to get there, and the location(s) where they observe key equipment or measuring points.

Our wayfinding for safeguards recommendations, based on the cognitive science research, are provided below.

Maintain Active Awareness. In one study on the impact of navigational aids on individual wayfinding activities, researchers found that GPS users travelled more slowly and longer distances in a route navigation task than users of paper maps or experience-based navigation (in which people learned a route from an experimenter) [58]. The study found that GPS users made stops to re-orient themselves more frequently than paper map users, and map users made stops more frequently than experience-based navigation participants. Participants were equally able to reach their end route regardless of their navigation aid. We recommend that when navigating to an unfamiliar nuclear site, inspectors familiar with the site actively engage with newer inspectors to teach them where the site is. For first-time or less familiar visits, we encourage the paper-based maps rather than GPS.

Use Landmarks. One study found that the use of landmarks in navigation instructions help orient people within in an environment and support the development of a cognitive map [59]. The authors recommend providing instructions that include landmarks and using those landmarks to re-orient one's self during navigation for more holistic understanding of an environment. If navigational aids such as GPS are to be used, the authors recommend a system that will reference landmarks in map visualizations. In a similar study, researchers found that local landmarks (e.g., a landmark within a facility) improve route knowledge, while global landmarks (e.g., external but nearby parking lots, rivers, or mountains) improve the broader knowledge of an area's layout [60]. These types of knowledge contribute to different aspects of wayfinding capabilities. The combination of both local and global landmark features improves performance in both route and survey tasks. The authors recommend including both types of landmarks on maps for best performance. For maps the IAEA controls (such as those provided to IAEA and then sent with inspectors or those created internally), we suggest emphasizing both local landmarks within a facility and global landmarks.

Avoid Distractions. One study investigated the impact of secondary tasks (activities participants are asked to complete during the primary activity) on the encoding of wayfinding information [57]. In the study, participants were led through a virtual path while completing a spatial, verbal, or visual secondary task. Both spatial and verbal secondary tasks interfered with spatial encoding, such that participants in these conditions were more likely to get lost when they repeated the path than those in the visual secondary task or control condition. Based on these findings, we recommend that safeguards inspectors being escorted through an unfamiliar area ask to stop momentarily if they need to pay close attention to a conversation or assess their spatial surroundings.

Use Your Most Efficient Map. In a wayfinding experiment conducted by members of this research team, we designed our task to address the unique needs of safeguards inspection environments, specifically: it was conducted in an indoor, complex industrial environment using guided/passive navigation, and participants were given paper maps to use. Our results showed that individuals with a *low sense of direction* perform worse when using maps on wayfinding tasks—such as developing survey knowledge of a facility—even if the map is studied prior to the navigation task [61]. Our results further showed that individuals with a *good sense of direction* perform better on some wayfinding tasks—like retracing their routes—when using a map. But on other aspects of task performance, such as situational awareness, the map provides no value to those with a good sense of direction and can even be detrimental to performance. Individuals who have a good sense of direction should study a map prior to an inspection if possible, and refer to it in only a limited way during on-site activities to avoid distraction [61]. We further recommend that if wayfinding is necessary during a team-based activity and involves placing important equipment in specific locations or retracing routes, the map should be designated to one member of a team, preferably one with a good sense of direction.

Train on Spatial Navigation Skills. One study found that during wayfinding activities individuals with a poor sense of direction pay less attention to spatial features, landmarks, and orientation than those with a better sense of direction [62]. The authors hypothesize, but have not experimentally confirmed, that additional spatial navigation training could support acquisition of some of these wayfinding skills. We recommend training safeguards inspectors or others who perform in-field activities on basic wayfinding skills.

Assess Your Abilities. Many studies have confirmed that an individual's sense of direction is highly indicative of their performance on wayfinding tasks. Self-assessments such as the Santa Barbara Sense of Direction (SBSOD) scale indicate that people do well in assessing their own capabilities [63]. We recommend that individuals know their own abilities.

11. Working in a Multilingual Environment

Language serves two essential purposes for communication: a) receiving, decoding and comprehending input (from external sources); and b) expressing and producing encoded language output (for external sources) [1]. Language is essential for communications—both verbal and written. One's primary language is referred to as L1, their secondary language L2, and so on. According to Kroll et al. [64], "being bilingual is not only about acquiring and using a second language (L2), but also about the ways that the native or dominant first language (L1) changes in response to the L2." Further, Kroll and colleagues suggest that the use of two languages "may enable bilinguals to develop special expertise that extends beyond language into cognition, shapes the brain networks that support cognitive control, and provides cognitive resources that are protective when individuals are old or cognitively impaired" [64]. Working in a multilingual environment poses unique challenges.

Figure 10: Language is essential for oral and written communication, as it is used to both encode outgoing messages for others and decode messages from external sources. People who are multilingual can communicate in more than one language.

The operating language of the IAEA Department of Safeguards is English. However, many safeguards staff members are not native English speakers, and therefore may have differing degrees of fluency in the English language.

Inspectors often speak different languages in the field, and many staff communicate with stakeholders in other languages. Additionally, analysts search and process information in many different languages, and multilingual ability is highly sought after for this job category.

Our safeguards recommendations for working in multilingual environments based on cognitive science research are below.

Be Aware of Context. One study highlighted the importance of nonverbal communication skills when working with speakers of multiple languages, for improvements to an individual's overall communication abilities, awareness, intelligence, and social interaction [65]. Other researchers found that when following instructions from non-native speakers, listeners rely more on context for interpretation [66]. We recommend that in addition to awareness of the content that individuals are communicating, they also pay close attention to nonverbal communications and the cultural context in which they are being displayed.

Use Multiple Forms of Communication. Research from Lev-Ari [66] suggested that over-relying on context rather than actual language, when interpreting directions from a non-native speaker, caused errors in an item-selection task. We recommend that anyone communicating in a multilingual environment—whether they are a native or secondary speaker of the language—ask for clarification when terms are ambiguous or could be misunderstood, or use additional methods of communication such as summarizing and using visual aids.

Gain Proficiency for Reduced Anxiety and Better Performance. In one study of advanced-level language learners in university-level Spanish courses, the advanced-level students reported lower levels of anxiety related to reading comprehension tasks and follow-up activities than introductory and intermediate-level students [67]. The researchers found that although stress had been found to impair comprehension in lower-level student, it did not have the negative effect on advanced students. This indicates that increased proficiency in operational L2s improves performance due to both comprehension and communication abilities, and the lesser impact from the stress of working in L2. We recommend that safeguards practitioners working in L2, L3, or beyond continue to practice and take coursework, if available, to support better performance.

12. Conclusion

International nuclear safeguards practitioners carry a heavy cognitive load, and their inherent potential for human error could lead to negative outcomes for the global community. Though humans will always make some errors, we can learn how to best support and enable human performance from the vast corpus of cognitive science literature. While the recommendations here may not be relevant for all safeguards verification activities, and may have unintentionally excluded relevant elements of the cognitive science domain, we hope that the recommendations provided here are both relevant and actionable to best support human performance across a range of safeguards tasks. Future research explicitly testing unique safeguards scenarios or environments, and using real safeguards practitioners, will continue to add value to this emerging domain of applied cognitive science for international safeguards.

13. Acknowledgements

The authors thank Jason Bolles and Haley Norris, of Sandia National Laboratories, for their tireless graphic design to support this work. The authors also wish to thank our peer reviewers for their thoughtful feedback. This research was supported by the United States Department of Energy's National Nuclear Security Administration Office of International Nuclear Safeguards (NA-241).

This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

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