Human Error & the Challenges of an Aging Workforce

Considerations for improving workplace safety

By Joel M. Haight

MANY OF TODAY'S INDUSTRIAL PROCESSES are complex and their operation requires employees to be in good physical and mental condition. Safe and efficient operation places high demands on memory, vision, range of motion, strength, decision making and reaction capabilities. Errors can lead to catastrophic events, potentially involving loss of life. A body of literature suggests that older people are less likely to respond quickly to upset conditions; less likely to see critical aspects of the process changing; more likely to become fatigued; and less likely to function at full strength or full alertness for the whole shift.

Joel M. Haight, Ph.D., P.E., CSP, CIH, *is an assistant professor in Penn State University's Dept. of Energy and Geo-Environmental Engineering. He holds a Ph.D. in Industrial and System Engineering and a Master's in Industrial Engineering, both from Auburn University. Haight worked as a safety engineer for Chevron Corp. for 18 years before joining Penn State. In addition to human error research, he also conducts research in the areas of safety program effectiveness and leading indicators. Administrator of ASSE's Engineering Practice Specialty, Haight is a professional member of ASSE, AIHA and the Human Factors and Ergonomics Society.*

While many human functions deteriorate with age, one important parameter would seem to help improve performance. Intuitively, one might expect diminished capacity to result in diminished job performance. However, one might also expect experience to moderate an increase in the error rates of older workers. For example, the experience level of older workers would seem to make for a controlled, efficient and effective response to dangerous upset conditions. However, the research literature is equivocal on the subject; therefore, more research is needed in this area across all workplaces.

Until this is fully understood, from a practical point of view, it makes sense to try to better understand the needs of various segments of the workforce and adjust accordingly. If industry representatives understand the age profile of the workforce, theoretically, adequate consideration can be given to work assignments, workhours, workspace design and performance expectations relative to the age of the workers. For example, the need for good vision, good reaction time, good memory, quick reflexes, full strength and range of motion would be considered when making job assignments. In positions that require a high level of experience, efficient planning and forecasting, and measured effective responses, workers who possess those attributes may receive consideration. Knowing worker capabilities also allows management to redesign tasks and positions to account for workers' limitations.

This article is written purely from an engineering point of view. It is not intended to present information to be used in hiring or not hiring any person for a particular job due to real or perceived loss of capacity. The only intention is to present information for consideration in task design and implementation. This article offers insight regarding the range of capabilities in an individual workforce and presents options for how to use workers to the best of their capabilities. It also poses several questions that need to be answered and suggests areas where more research is needed.

The Statistics

The workforce is aging. The American Assn. of Retired Persons (AARP) suggests that between 2000 and 2020, the number of those in the 55 to 64 age range will increase nearly 40 percent, and the number of those in the 65+ category will increase more than 40 percent. This will occur while other age brackets (25 to 34, 35 to 44 and 45 to 54) will decrease in size (AARP). According to Bureau of Labor Statistics (BLS), in 2002, those in the 25 to 54 age range made up approximately 76 percent of the working population, while those in the 55 and older age range make up approximately 13.6 percent of that population. BLS also shows that in 2001, those in the 25 to 54 age range experienced nearly 75 percent of the recordable injuries involving days away from work, while those in the 55 and older age bracket experienced only 10.4 percent of such injuries (BLS). (The remaining percentages come from those in the 14 to 24 age bracket and from those injuries in which age was not reported to BLS.) Does age affect error rates and thus injury and accident rates? This article explores physical and mental capacity loss as well as experience level in an attempt to answer this question.

Vision Decrement & Hearing Loss in Older Workers

Visual acuity deteriorates with age (Shinar and Schieber). Some visual problems and diseases experienced by older persons include loss of light transmissivity, oculomotor (ability to move the eyes in following visual targets) impairments, cataracts, glaucoma and age-related macular degeneration (damage or breakdown of the macula, a small central point of the light-sensing retina that processes the sharp central vision used for reading and similar detail tasks) (Klein). According to Shinar:

- All visual functions deteriorate with age.
- The amount, rate and age of onset of deterioration vary widely among the visual functions.
- Deterioration in static acuity is not significant before the age of 60, whereas deterioration in the more complex tasks (acuity for a moving object, dynamic acuity, detection of lateral motion, detection of in and out movement) begins much earlier and accelerates faster with increasing age.
- The age-related average deterioration is accompanied by a marked increase in individual differences (Shinar).

Shinar's research involved subjects from the general population, however, they would represent members of the working population as well as members of the retired and nonworking population.

Much of the research concerning vision and older people has been performed in the area of driving. Many of these results can be extrapolated to other tasks that require similar levels of visual acuity. In driving tasks, Shinar discussed a small but consistent correlation between phototropic acuity (ability to adapt, respond to and see in conditions of changing light) and accident involvement. This relationship is strongest in older drivers. Nighttime legibility distances of highway signs for drivers over age 60 was 65 to 77 percent of the legibility distance for drivers under age 25 with equal phototropic acuity (Sivak, et al).

Dynamic visual acuity (DVA) is the ability to resolve details of a moving target (Shinar and Schieber). DVA is more closely associated with accident involvement than static acuity [Burg(a)]. Since DVA deteriorates at ages under 60, task requirements involving visual acuity of highly mobile information or controls may be better reserved for younger people. Since DVA deterioration is a gradual process, it is difficult to pinpoint the age of onset and the age when the deterioration becomes serious enough to affect job performance; as a result, it is difficult to say what percentage of the workforce has experienced DVA. It may be fair to conclude that since DVA is thought to begin around age 45, close to 30 percent of the workforce would be potentially affected (estimated from BLS statistics). Other abnormalities found in older people that have been correlated with increased vehicular accidents include perception of angular movement; movement in depth and visual field; eye-tracking movement; glare sensitivity; color vision; contrast sensitivity; and scotopic vision (ability to see in dim light) [Burg(b); (c)].

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Safe performance in driving, as well as in operating a process in a nuclear plant or oil refinery from a computer screen, requires a person to rapidly search a visually dense area, extract critical information and respond in an appropriate manner (Ho, et al). Because older people have a reduced field of view and are more susceptible to scene clutter, they make much larger eye movements to scan the entire scene (Ho, et al). Clutter (nontarget information in the visual field) and search deficiencies make it more difficult for older workers to see critical information and easier to miss it because of the clutter. This problem is exacerbated by low illuminance (Chrysler, et al). Response times increase as clutter increases and illuminance decreases. Since lighting and presentation of information can be controlled, it appears that these systems can be designed to account for age. For example, controls should be well-lit; provide high contrast between measured or monitored parameters; present as little clutter as possible (Ho, et al); and not be dependent on fast response times.

Age-related hearing loss (presbycusis) is thought to begin at about age 35, but becomes more pronounced with advancing age (Olishifski and Standard). Operating industrial processes requires the use of all senses, and hearing is essential. Often, emergencies are first detected by auditory stimulation, such as that provided by alarms. Hearing emergency alarm signals, however, is not the greatest concern for older workers. It is of greater concern from an error standpoint, when the signal is more subtle than a wailing siren. Research performed in a multiple task environment shows that older workers scored significantly lower than younger workers in auditory task performance.

By understanding the age profile of the workforce, consideration can be given to tasks, workhours, workspace design and performance expectations relative to the age of the workers.

However, while older workers had reduced tone detection sensitivity as well as hearing loss, the lower scores were not completely attributable to hearing loss. Older workers show poor auditory discrimination performance because of a reduced ability to strategically allocate attention toward performance of auditory monitoring (Sit and Fisk). It is not known why auditory monitoring tasks receive lower mental priority than other tasks, but this finding indicates that the demand on the auditory system of older workers should be reduced when designing control systems.

Cognitive Functioning Decrement in Older Workers: Mental Processing, Decision-Making Memory & Reaction Time

Increased age is frequently associated with lower performance on various measures of cognitive functioning [Salthouse(a)]. Many questions are posed in the literature about differences in age-related performance in cognitive functioning. These include:

•Are the differences confined to novel or abstract tasks?

•Are these differences reduced or absent in measures from familiar or concrete tasks?

•Can age-related differences be attenuated or eliminated with additional practice or training?

•Do these differences disappear when individuals have extensive experience with relevant activities [Salthouse(a)]?

It has been suggested that experience can be a moderator of potential errors due to decrement in cognitive functioning. However, the literature is not conclusive [Salthouse(a)]. Other researchers also show that there is decrement in memory, reaction time, decision-making time and general mental processing time.

For example, in a nuclear power plant, operators monitor plant status (temperatures, pressures, flows, levels, etc.). As these parameters change, operators must determine whether the change is within operational limits—they are looking for any limit exceedance and the rate of that change. Operators have to detect (visual, auditory, tactile) a change in process conditions, then they must assess and interpret (mental processing, decision making, etc.) the change data to determine whether it is normal. Once they decide what to do, they must respond (vision, strength, range of motion, etc.) to address the change. They must make decisions quickly and act decisively to either address another parameter or take action to correct an abnormal situation (Mumaw, et al). These performance parameters are affected by age.

Such processing requires cognitive functioning. Often, operators must monitor and respond to two or more inputs. They must make decisions and execute more than one action in response. Decision making can be a problem among older adults, as they make decisions more slowly than younger adults (Walker, et al). In driving, research shows that when taking a trip older adults take longer to make decisions about route selection, especially when route speed increased. Confidence about the decision made was also a function of route speed (Walker, et al). Slower decision making is exacerbated when there is perceived time pressure.

However, it is noteworthy that decision quality did not seem to be affected by age. When an older person finally made a decision, it was usually as correct as those made by younger people (Walker, et al). Therefore, as long as the task is familiar and there is sufficient time to make the decision, the performance outcome of older workers should not decline. The problem in industry is that there may not be sufficient time to allow the older worker to respond.

Depending on task complexity, older adults are slower to respond. Response speed has a linear relationship with task complexity (Sit and Fisk). The more complex the task, the slower the response time. Older adults also have more difficulty managing or coordinating multiple tasks (Korteling). If a particular response requires more than two tasks at once or that they be performed quickly, an older person may have difficulty prioritizing the tasks and keeping all tasks active. Some research has suggested that age-related difference in performance of multiple tasks is reduced through training (Rogers, Bertus and Gilbert). Other research has suggested that performance is improved further if task performance order is flexible—meaning the worker can decide what order to perform tasks without penalty (Baron and Mattila). It is also interesting that performance difference between older and younger workers decreased in a multiple-task environment when a specific task was emphasized as more important than others (Sit, et al).

Older adults also allocate attention differently than younger adults. Multiple task performance research indicates that with age-related limitations in cognitive processing, as well as other physical sensitivity reductions, age-related decline in performance is most attributable to the declining ability to manage or coordinate multiple tasks (Sit, et al). This is more pronounced when task complexity is higher, tasks are unfamiliar or time demands are short.

Therefore, given that older adults process information more slowly, have working memory deficits or have inhibitory problems, adjustments must be made in task design (Sit, et al). Key considerations include allowance of longer response time, additional practice to increase familiarity, frequent refresher training, frequent reinforcement of task priority, reduction in the need for simultaneous performance of multiple tasks, or designing the system to be operated with low sensitivity to task order.

Training and learning warrant further discussion. In emergencies or situations where response time requirements are immediate and actions required are simultaneous and numerous, humans need to rely on "automatic attention responses" (AAR) to bring the situation under control. An AAR is a well-learned response to a stimulus that does not need to be mediated by attention. It occurs immediately, unconsciously and even involuntarily in the presence of an eliciting stimulus (Gilbert and Rogers). A simple example would be turning toward a person when s/he calls your name. If alarm A activates, close valve B. Such responses result after extensive, consistent practice.

Research shows that older adults, while they improve with extensive and consistent practice, do not develop new AARs (Gilbert and Rogers; Fisk and Rogers; Rogers; Rogers, Fisk and Hertzog). Therefore, younger people may be better able to handle the multiple task demands of an emergency because they can accomplish some tasks without demand on their attention (assuming they have developed appropriate AARs). In older adults, while training and practice result in improvement, a multiple-task environment will continue to demand their attention. The likely error would, therefore, be one of omission. However, if the task becomes disrupted and a particular AAR is no longer appropriate, a younger person would be more likely to make the error. Because older adults keep their attention engaged, they exhibit better performance when the situation requires flexibility in response to changing stimuli (Gilbert, et al).

The results of Korteling's 1994 study indicate a pervasive tendency, although indistinct, toward decreased psychomotor learning and unlearning capabilities in later adult life. However, older adults respond positively to training and practice. Even though they learn differently than younger adults, this can potentially be overcome with more frequent hands-on refresher training. One might also implement frequent emergency response drills with hands-on activities included for older adults. With experience, practice and training, it is possible that age-related error differences may be reduced.

Physical & Mechanical Limitations in Older Workers

Physical capabilities decline with age. Capabilities that relate to performance of industrial tasks include strength, range of motion, speed of movement, fatigue, motor skills and healing after injury. Around age 50, it is thought that perceptive-motor capacities may begin to decline. For example, in evaluating the vehicle cockpit in reach motion posture research, Chaffin, et al, showed that older adults tend to exhibit a more conservative reach. They kept the elbow closer to the torso and did not elevate the shoulder (abduct) as much as younger participants. Although this conservative posture is not explained, it could be due as much to concern about an overextension injury and perceived lack of strength as to a true loss of range of motion. The difference is more pronounced in longer reaches. Either the older person does not reach the control or s/he accidentally manipulates a closer control, which could force the wrong response from the system (Chaffin, et al). Therefore, reach should be minimized for tasks performed by older workers.

Decision making can be a problem among older adults, as they make decisions more slowly than younger adults. This is exacerbated when there is perceived time pressure.

Driving and similar tasks (e.g., operating a large piece of machinery) require responding continuously to spatial and temporal information from the environment and the equipment. In doing so, one must coordinate movement of the head, neck and upper and lower limbs (Stelmach and Nahom). Motor control is critical when one must brake, steer, turn, change lanes, merge, recover from a skid, start a pump, drop the level in a storage tank, etc. (Stelmach, et al). One of the most pervasive findings in age-related research is that motor performance slows with aging [Salthouse(b)].

Age-related motor impairments have been linked to loss of sensory receptivity, decrease in muscle mass and elasticity, decrease in bone mass, and reduction in central and peripheral nerve fibers. These changes affect a worker's ability to control movement rapidity and accuracy (Stelmach, et al). Research by Stelmach, et al, evaluated a driving task, but because it was basic to all human motor capability, the results should extrapolate to similar tasks that require a motor response to a stimulus. The researchers found that there is age-related slowing in all facets of movement initiation—including response preparation, selection, programming and complexity. Movement execution was also found to slow with aging (Stelmach, et al).

The literature also shows a disturbing trend in fatalities from falls. Fatality rates from falls increase beginning in the 45 to 54 age group and account for 20 percent of the fatalities among workers over age 55 (nine percent for all other ages) (Agnew and Suruda). In 1981, Root reported that one-third of all compensable injuries to workers over age 65 were due to falls (Root).

It appears that ladders are most often involved in falls among older workers. Researchers suggest that this may be due to a decline in balance and coordination among these workers. Loss of control of postural stability, which could be related to increased risk of falling, tends to begin in the 50 to 60 age group (Sheldon). Reduced strength may also affect an older worker's ability to recover balance or lost footing to avoid a fall (Spirduso and MacRae). Fatigue, which is thought to occur more readily in older workers, may

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also be a causal factor (Agnew, et al). Adapting the workplace for an aging workforce may, therefore, involve reducing the need for elevated work and eliminating the use of ladders where possible.

As noted, in industrial settings, workers must often operate various controls. This could involve turning valve hand wheels, pushing or pulling levers, and turning dials or knobs of various shapes and sizes. In a 1988 study, elderly females were found to have difficulty generating enough torque in water faucet handles of various shapes (Bordett, et al). It has been established in the literature that older workers experience a decrease in strength. Therefore, any design that does not allow an older worker to apply maximum strength would not be suggested. A large paddle-wheel-type handle design is compatible. The worst of the designs studied was a multipoint design that did not permit subjects to develop a strong grip (Bordett, et al).

Given the reduced strength in older workers, any design that compromises grip, leverage or mechanical advantage would not be suitable. Bordett, et al also reported that studies conducted by Nichols, Johnson and Woods show that a lever control is preferred over knobs because twice as much torque can be exerted. If one cannot operate controls adequately, errors can be expected.

Quantification of Error Potential & Experience Offsets

Several intuitively expected hypotheses proposed in the literature say that experience moderates the error rate difference between younger and older workers. A complete review of the existing research, however, does not provide unequivocal proof of these hypotheses [Salthouse(a)]. Several researchers have found that many age-related performance differences between older and younger people are reduced when task familiarity and experience are considered [Sit and Fisk; Walker, et al; Salthouse(a)].

However, this area has not been thoroughly explored in an applied, industrial, task-based setting. Quantification of the difference reduction or offset in error rates relative to experience level has not been accomplished in age-related performance research. In general, research has shown that while errors increase among older adults as they accomplish life-skill tasks, the same losses have not been shown in performance of work tasks. In other words, decreased capacity with potential increase in error rates does not necessarily lead to performance decrement at work.

In driving research, experience has been shown to result in improved navigation performance; this is due to improved driving strategies that develop as experienced drivers are able to devote more attention to the navigating task. They make fewer glances of shorter duration at navigational aids, leaving more of their "spare visual capacity" to focus on improved performance. Inexperienced drivers must devote much of their spare visual capacity to concentrate on the newness of the task—the novelty effect (Dingus, et al).

Unfortunately, similar research has not been conducted in industrial settings. Salthouse claims that, at the time, existing cognitive research was still too equivocal to allow firm conclusions to be reached that age-related differences in performance of familiar activities are smaller than those on novel activities [Salthouse(a)]. There does not appear to be an update to this conclusion.

Motor learning research may be another body of literature that supports the "experience is an error rate moderator" hypothesis. Attention is one human process variable that affects physical and mental performance. As noted, attention capacity is a performance variable that appears to deteriorate with age. Some research proposes that attention is related to the idea that people have a limited capacity to process information (Magill). This raises several questions: Why is it easy for a skilled second baseman to effectively do all that is required in completing a double play when a beginner has so much difficulty? Why can a skilled typist carry on a conversation with someone while continuing to type? Why does a physical therapy patient tell the therapist not to give him/her so many instructions at once? Why is a skilled gymnast or dancer able to smoothly and effortlessly carry out a complex routine whereas a beginner is rough and inefficient (Magill)?

The intuitive answer is that experience in motor tasks decreases the need for attention capacity. Magill mentions the limited capacity theory proposed by Kahneman and states that while there is a limited capacity for attention, several factors affect available capacity. These include a person's arousal level, enduring dispositions (demand on involuntary attention), momentary intentions and evaluation of demands on capacity.

While aging seems to result in a general decreased attention capacity and other age-related limitations also reduce the factors which affect capacity, the literature implies that experience reduces the need for attention capacity. This may be true for pure motor skills, but has not yet been unequivocally proven in industrial task performance. Although some suggest that research in an applied setting will be a challenge due to the difficulty of maintaining a consistent experimental setting [Salthouse(a)], pursuing this line of research is no less important.

Conclusions & Suggestions

As this literature review shows, older workers are at a disadvantage when it comes to overall task performance. They are more likely to make errors than younger workers unless adjustments are made to the workplace, task design, time demands or strength requirements. Older workers also have decreased capacity in areas such as vision, hearing, strength, balance, memory, response time, action time, decision making and mental processing. Although much of the literature does not explicitly state that older workers suffer increased error rates, it does implicitly show this to be a concern.

Some literature shows that older workers enjoy the benefits of more experience, which may allow for more efficient execution of their tasks. Some research also shows that experience serves to moderate the difference in task performance between older and younger workers. Task familiarity, training and practice seem to moderate the performance deficit in older workers as well. However, evidence suggests that in an applied work setting, not enough is yet known to claim this across the board. While much of the research has been conducted in a laboratory setting and often has involved driving tasks, it can, at least partially, be extrapolated and applied to similar activities performed by operators in industrial settings such as a nuclear plant, oil refinery, chemical or pharmaceutical plant, or paper mill.

Although the onset of age-related performance decrement begins to occur in those over age 45, it does not appear to become significant until age 50 and above. If a workforce has a significant number of employees older than age 50 (e.g., more than 10 percent), work setting changes may be warranted. An encouraging finding is that age-related errors and performance decrement appear to be manageable. Some general suggestions for consideration in accommodating older workers and reducing the likelihood of errors include:

1) Improve illumination.

2) Eliminate heavy lifts, elevated work from ladders and long reaches.

3) Design work floors and platforms with smooth and solid decking while still allowing some cushioning.

4) Remove clutter from control panels and computer screens.

5) Reduce noise levels.

6) Lengthen time requirements between steps in a task.

7) Reduce the need for simultaneous performance of two or more steps in a task.

8) Increase the time allowed for making decisions.

9) Consider necessary reaction time when assigning older workers to tasks.

10) Provide opportunities for practice and time to develop task familiarity.

11) Educate industry about the needs of older workers.

Some research shows that experience moderates the difference in task performance between older and younger workers, as may task familiarity, training and practice.

While these suggestions focus on age-related error concerns, several questions must be answered before age-related loss of capacity can be accounted for. Key questions might include:

- How much illumination is enough and for what ages should adequate illumination be targeted?
- NIOSH has a lifting guide to ensure that workers do not strain their backs during heavy or awkward lifts. How should that be adjusted for age?
- How much floor cushioning is needed and what is the age-related offset for stability versus cushioning?
- How much computer screen clutter is too much and at what age do workers require "less" clutter?
- While OSHA has a guideline for protecting workers' hearing through limiting exposure, how much more should it be reduced to help older workers concentrate?
- Which and how many control signals should be changed from an auditory signal to help ensure that older workers do not overly reduce priority of tasks associated with auditory instructions or signals?
- How much time do older workers need to make decisions? Is it also dependent on the number of steps in the task?
- Since multitasking is common, how many simultaneous steps are too many? Is there a difference in how many steps can be handled by a 45-year-old and a 50-year-old or maybe a 58-year-old?
- Research has shown that decisions made by older workers, if given enough time to make them, were as good as the decisions made by younger workers. What if there is not enough time to allow better decisions to be made? How much time is enough? How much time is necessary to respond to a stimulus? How do we consider or quantify the need for additional time for older workers to process the stimulus (to make the decision that a motor reaction is needed) and to generate the motor response action?
- Experience is critical to helping older workers maintain error-free performance even as their physical and mental capabilities are becoming limited. However, how much experience is needed to offset the potential increased error rate? Based on the research reviewed, one might expect older workers to experience higher injury rates. However, AARP and BLS data do not support that hypothesis. Is this due to the "experience offset" concept or some other phenomenon, such as adopting a more conservative approach to completing work tasks?

This list of suggestions and questions is designed to encourage readers to think about the needs of an older workforce. Unfortunately, there are more questions than suggestions. While specific, quantified answers may not be available for all of the questions

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posed, additional consideration during the design process of workers' age should result in a workplace that experiences fewer errors due to age-related limitations.

Implementing any of the suggested improvements would likely benefit all workers, not just older workers. However, the current literature does not quantify this benefit, making it another topic for future research. Building codes and design criteria often do not consider the limitations and constraints of older workers, but design engineering groups should be educated about these needs. With respect to task design, more can be done to account for older workers. More research is needed in this area to help fill in the quantification of experience gap as well as more industry-applied information. ■

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