Applied Cognitive Psychology, *Appl. Cognit. Psychol.* **29**: 425–435 (2015)
DOI: 10.1002/acp.3121

Great Expectations: Perceptual Challenges of Visual Surveillance in Lifeguarding

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Summary: The presence of lifeguards on beaches and at pools has the potential to prevent many drowning incidents. This article examines the visual components of the lifeguard's job, discussing some of the major challenges they face during surveillance. These include optical challenges (turbidity and turbulence of the water, light refraction, and glare), scene challenges (elevated set size affecting clutter and perceptual 'blindnesses'), stimulus challenges (searching for multiple targets that are complex, dynamic, ill-defined, and rare), and attentional challenges, including but not limited to vigilance issues. The differences between basic laboratory research and the lifeguarding task are explored, with recommendations for future study. Copyright © 2015 John Wiley & Sons, Ltd.

On 14 July 2010, approximately 175 teenage boys enjoyed a day of swimming at a local pool in Pella, Iowa, as part of a Fellowship of Christian Athletes camp held at Central College. When it was time to board busses to return to their rooms, two boys were discovered missing. A 15-minute search culminated in a tragic discovery—the bodies of two of the boys (ages 14 and 15 years) were discovered motionless on the bottom of the pool. Attempts to revive them failed (Belz, 2010).

The drownings seem more surprising considering the circumstances under which they occurred. At least 10 lifeguards and 20 camp counselors observed the boys while they played. Nobody was aware of their drowning—not even the other boys who were presumably swimming near them as they experienced difficulty and sank in the water. In situations like this, the immediate public reaction is to blame the lifeguards for their failure to notice this very serious event—fatal drowning incidents in lifeguarded facilities are rare (United States Lifesaving Association, 2010), so it may appear as though missing a drowning is abnormal and stemmed from some failure on the lifeguard's part. The grieving family may then sue the lifeguard or facility for negligence (see Hronek & Spengler, 2002). But, when the task of lifeguarding, or any surveillance task, is examined from a visual cognition perspective, it is clear that lifeguards face major challenges due to known limits in perceptual processing and attention.

LIFEGUARD TRAINING

Lifeguards are trained extensively before certification. The American Red Cross, a leader in lifeguard training and certification in the USA, also requires individuals to be able to swim at least 300 yards without stopping and to dive to a 10-ft depth (demonstrating physical fitness to perform a rescue). Per Red Cross guidelines, individuals must attend 30 hours of intensive training on lifeguard professionalism, surveillance, rescue technique, first-aid, and cardiopulmonary resuscitation (CPR). After completion, they may seek certification by passing both written and water tests where rescue technique and CPR can be evaluated. Surveillance, arguably the primary component of the lifeguard's task, is not evaluated beyond the written examination.

During training, individuals are taught to locate and identify individuals who are drowning or experiencing distress. Drowning is asphyxiation in an aquatic environment, and lifeguards are trained to look for key behaviors of individuals who may be drowning. A *passive drowning* occurs when an individual loses consciousness in the water (American Red Cross, 2007). If the person's nose and mouth are submerged, water could enter the trachea or lungs, making oxygen absorption impossible leading to brain cell death (e.g., Brewster, 2003; YMCA, 2001). An *active drowning* occurs when an individual begins to struggle at the surface of the water, exhibiting a set of behaviors known collectively as the *instinctive drowning response* (e.g., Pia, 1974). These behaviors include a tilted head, vertical body position, flailing arms, no supporting leg kick, and no locomotion through the water. This struggle only continues as long as the patron's energy permits, which can be less than a minute. If no rescue is imminent, the patron may slip under the water surface and eventually lose consciousness. Contrary to popular media portrayals, individuals who are struggling focus all their energy and attention on the task of breathing in the few seconds their mouth is above water; therefore, they are generally unable to call out for help, and it is the responsibility of the lifeguard to perform a rescue immediately (Vittone, 2010). An individual in *distress*, on the other hand, is struggling yet capable of treading water or floating and calling out for help. A distressed individual should be helped immediately; in the absence of help, he or she could begin to drown.

LIFEGUARD EFFECTIVENESS

Societal expectations for lifeguards are quite high: quickly identify drowning people and quickly rescue them. A missed target for a lifeguard can result in the death of another person. While drowning remains the leading cause of death in boys 1–4 years old and the second leading cause of death in girls of that age (Xu, 2014), many if not most of these deaths occur in locations that are not monitored by lifeguards

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(e.g., bathtubs and private swimming pools). Unfortunately, detailed reporting of death by drowning in lifeguarded facilities is rare. One source of statistics is the United States Lifesaving Association (USLA, 2010), which estimates that a person's risk of death by drowning at their affiliated facilities is only 1 in 18 million when lifeguards are on duty. A caveat to this statement is that sites do not track individuals once they have been transported to the hospital, so it is unclear how many of the rescued sustain lifelong injuries or death from their drowning incident.

The statistics earlier highlight the success of lifeguards at USLA-affiliated facilities, but they only represent a small number of swimming sites that may not be representative of all venues. Relying on newspaper articles, Pelletier and Gilchrist (2011) determined that between 2000 and 2008, there were a total of 140 deaths in lifeguarded pool facilities in the USA. Unfortunately, there are no data on the number of successful rescues over the same time period.

In this review, we suggest that limitations of visual conditions and information processing may play a significant role in the failure to detect the critical events that require action. Specifically, there are challenges due to optics, scene context, what one is looking for, and attentional limitations. Here, we consider these limitations in detail and describe how they might affect lifeguards and offer suggestions for future study of lifeguard surveillance that could lead to more effective guarding. It is important to note that while this review focuses on lifeguard surveillance, many of the processing limitations we discuss and suggestions we offer can apply equally to other surveillance tasks.

PERCEPTUAL AND ATTENTIONAL CHALLENGES FOR LIFEGUARDS

Optical properties

One of the challenges that lifeguards face is the relatively poor quality of some of the visual information with which they must work. Visual images are formed when light is reflected from surfaces of objects and reaches the retina of the viewer. Anything that alters the path of light between the object and the eye can disrupt the image. The properties of water can disrupt the image of objects in the water in three different ways. First, light reflecting off objects below water is scattered by particles in the water, increasing turbidity (lack of clarity or 'cloudiness') of the water. This is the functional equivalent of adding visual noise to the image of anything in the water (e.g., Baranov-Krylov, Shuvaev, & Astashchenko, 2011). Turbidity is often, although not always, low in pools. It is a bigger problem in open-water environments like lakes and the ocean. Second, light that passes through the air–water interface is refracted, disrupting the images of objects in the water. Refraction through multiple surface angles of turbulent water can render objects virtually invisible as the coherence of the image is completely disrupted (Griffiths, 2006). Third, light from an overhead source (e.g., the sun or florescent lights) can reflect off the surface of the water, obscuring the image of objects below the surface as the mirrored surface of a one-way mirror does. Each of these factors can make it more difficult to see objects in the water.

Scene context

Lifeguards are responsible for sometimes large numbers of swimmers. A survey of lifeguards conducted by Griffiths, Steel, and Vogelsong (1996) revealed that 60% of lifeguards were often responsible for 50 or more patrons in their zone. Laboratory studies have demonstrated that searching through very large displays is difficult and may require up to several seconds to find the target (e.g., Wolfe, 1998a, cf. Neider & Zelinsky, 2008). This suggests that lifeguards faced with many patrons will take a long time to search through them. The American Red Cross (2007) recommends individual scrutiny for patrons being monitored, but this search process is likely to take a substantial amount of time as the number of swimmers increases.

A by-product of elevated set size in a limited physical space is that the scene becomes more cluttered. Visually, this is problematic because visual and attentional resolution is limited. Research has demonstrated that search through cluttered displays is more challenging than search through uncluttered displays (e.g., Rosenholtz, Huang, & Ehinger, 2012). Although chunking stimuli based on featural similarities can improve search performance (Neider & Zelinsky, 2008), it is unclear whether chunking would improve lifeguard detection of distress and drowning. As groups of patrons get larger, the struggle of an individual patron within that group may become hidden or masked by the varied activity surrounding him or her. Additionally, patrons around the drowning patron may not realize that he or she is drowning (American Red Cross, 2007; Vittone, 2010)

In addition to visual crowding, another problem emerges with increasing numbers of patrons. A lifeguard cannot attend to all patrons simultaneously; therefore, some patrons must necessarily be unattended for some period of time. Inattention to stimuli can produce what have been characterized as perceptual blindnesses in the visual cognition literature (e.g., Rensink, 2000; 2002; Simons & Rensink, 2005). *Inattentional blindness* (Mack & Rock, 1998) demonstrates that attending to one aspect of the scene—something that lifeguards must do constantly—can cause otherwise obvious, large, and significant events to go unnoticed (see Moore, 2009; 2010, for reviews). In one well-known example, Simons and Chabris (1999) asked subjects to view a video of two teams of players passing a ball to each other and to count the number of times that a given team passed the ball. This task required intense attentive visual processing of part of the scene. Under these conditions, about 50% of the subjects failed to notice that a person in a gorilla suit walked through the group. A more serious example was revealed in a study using a flight simulator, in which trained pilots failed to see an airplane that was on the runway on which they were landing because they were attending to a heads-up instrument display that was projected onto the windshield. Several of the pilots landed their plane right on top of the other (simulated) plane (Haines, 1991). Both the gorilla and the airplane were in the participants' direct field of view yet were not processed because they were not attended.

A related phenomenon is *change blindness*, which refers to the fact that observers can fail to notice (or be delayed in noticing; Rensink, O'Regan, & Clark, 1997) large and significant changes in scenes that they are scrutinizing (e.g., an airplane engine appearing and disappearing from a large jet), despite being highly motivated to detect those changes. Observers sometimes even fixate the change in the scene but still do not detect it (e.g., O'Regan, Deubel, Clark, & Rensink, 2000), suggesting that the problem concerns *attention*, not low-level visual processing. Finally, and particularly relevant to a surveillance task like lifeguarding, change blindness can even occur in the context of live human interactions. Simons and Levin (1998) found that subjects failed to notice when a person with whom they were talking exchanged places with a different (previously hidden) person after disappearing for a moment behind a door.

Research on inattentional blindness and change blindness highlights that attentive visual processing is required to process a complex scene, yet this attentive processing is limited in capacity and can therefore lead to a failure to notice unattended events or changes. The on-duty lifeguard faces several patrons who may be engaged in different aquatic activities. A lifeguard cannot attend to all of them simultaneously and must attend to each patron or group of patrons in turn. Yet, even if the lifeguard is thoroughly attentive to each one, a sudden change or disappearance in one patron may go unnoticed because the lifeguard had not been attending to him *at that very moment*.

An informal study at lifeguarded pools documented exactly this sort of failure (Brener & Oostman, 2002). In 2001, as part of an audit process, Ellis and Associates, an international aquatic safety and risk management firm, placed mannequins into pools that were being guarded by trained lifeguards. In each case, the mannequin sank and lay inert on the bottom of the pool, thereby presenting standard signs of a passive drowning. A total of 500 of these tests were performed at 90 different pools across the USA. Despite being apparently engaged in proper scanning behavior (verified by unobtrusive video recording), trained lifeguards failed to notice the mannequin within the 3-minute time limit on 14% of the tests. Moreover, the mannequin was detected within the 10-second period that is stipulated by an industry rubric, known as the *10/20 protection rule*, on fewer than 10% of the trials. The 10/20 protection rule states that lifeguards must detect signs of distress or drowning within 10 seconds of when they commence, and then engage in a rescue within 20 seconds of detection. The logic behind this rule stems from seeking to prevent hypoxia-induced brain damage by rescuing the patron as soon as possible. Given the limitations of human perception, however, it is unclear whether this goal is achievable. The fact that over 90% of the lifeguards in this study failed to meet this goal highlights just how difficult it is.

Stimulus properties

The main target in the lifeguard's search task is drowning and distress, but a second target is dangerous activities with injury potential. (Lifeguards are not merely life*savers* but life*guards* that can mitigate physical injury as well as drowning.) Surveillance for drowning and distress is generally considered to be the most important goal because of the risk of imminent death that can occur, but these other targets (with varying prevalence) must be responded to as well. Lifeguards are given a list of behaviors that are thought to indicate drowning and distress to aid their search, but many lifeguard professionals argue that not every drowning incident looks the same. Additionally, the dynamic nature of the lifeguard's search task requires continual updating of internal representations that are subject to attention and memory limitations. All of these considerations contribute additional challenges to the lifeguard's success.

Multiple targets with varying prevalence

Drowning and distress are rare events. A typical lifeguard may work an entire summer or longer and never see drowning or distress. Despite learning the behaviors of drowning in their instruction (and perhaps seeing video of drowning incidents, as in Pia, 1971), there are potential cognitive and behavioral consequences of never or rarely experiencing these events. This problem relates to many other real-world search tasks that have been studied within the visual cognition literature (e.g., baggage screening and radiology).

Lifeguarding, like many other occupational search tasks, requires detecting a target that occurs only rarely. Typical laboratory search tasks have a target prevalence of 50% and a miss rate under 10%. Wolfe, Horowitz, and Kenner (2005) found that targets present on 50% of trials in a simulated baggage-screening task were missed only 7% of the time but targets present on only 1% of the trials were missed 30% of the time. Importantly, this effect remained even when an incentive was offered for detection. Other researchers have explored the effect of prevalence in expert and novice radiologists and cytologists. Nakashima, Kobayashi, Maeda, Yoshikawa, and Yokosawa (2009) studied radiologists compared with novice undergraduates and found that the radiologists missed *no* rare cancer targets in X-ray images (although the overall miss rate was quite low in this study). Others, however, have found results similar to Wolfe et al. (2005) that experts perform as novices do with decreased accuracy in responding to rare targets, both in cytology (Evans, Tambouret, Evered, Wilbur, & Wolfe, 2011) and in baggage screening (Wolfe, Brunelli, Rubinstein, & Horowitz, 2013).

As noted, in addition to drowning and distress, a lifeguard must also search for dangerous activities to prevent injury to patrons. Many activities are dangerous to patrons—for example, horseplay, hanging onto other people, and running. Research by Menneer and colleagues (Menneer, Barrett, Phillips, Donnelly, & Cave, 2007; Menneer, Cave, & Donnelly, 2009) has indicated that searching for only two targets (sufficiently different from each other) produces a sizeable reduction in accuracy compared with search for a single target. This would suggest that the lifeguard will be challenged by their multiple-target search. Far worse, this effect is exacerbated if one target is more prevalent than another—Wolfe et al. (2005) found that when participants were searching for two targets, a prevalent one and an extremely rare one, 52% of the extremely rare targets were missed compared with 11% of the targets that had a more common 44% prevalence. Because Schwebel, Simpson, and Lindsay (2007) found that in one community pool, over 90 dangerous incidents occurred per hour, dangerous behavior occurs at a much higher frequency than drowning. Lifeguards may, by virtue of correctly locating and responding to these dangerous incidents, be less likely to detect the much rarer drowning incident.

To complicate matters, some lifeguard supervisors, in an attempt to crudely assess lifeguard attentiveness, have adopted the practice of throwing a poolside object—a rubber ball, plastic mat, etc.—into the water and time the lifeguard's detection and retrieval of the object (see Griffiths, 2003). Although the logic that motivates this exercise is compelling—ensuring that lifeguards are fully alert and ready to perform a rescue should one be warranted—it is not sound from a visual cognition perspective. The object becomes yet another target (one irrelevant to the real search task), and because of its increased prevalence relative to drowning and distress, responding accurately and promptly to it may actually decrease the possibility of detecting drowning incidents, which will be much less prevalent.

Requiring lifeguards to search for multiple targets has introduced another potential problem in cases where two targets are present simultaneously. Recent cognitive work (e.g., Fleck, Samei, & Mitroff, 2010) has investigated a phenomenon known as satisfaction of search, where under conditions of multiple targets, participants will stop their search after detecting only one target (e.g., Berbaum et al., 1990; Berbaum et al., 1991; Smith, 1967; Tuddenham, 1962), being 'satisfied' with finding one and terminating the trial before finding another. If this phenomenon occurred in the water, it would have detrimental consequences. The lifeguard might notice a dangerous event such as horseplay, respond to it, and then be unable to detect additional dangerous events. If another patron is drowning at that moment, he or she may go unnoticed.

Ill-defined targets with significant feature overlap with non-targets

Whereas most stimuli used in laboratory search tasks are simple, well-defined shapes (e.g., Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989), the behavior of a swimming person is much more complex. A single feature (such as flailing arms) is insufficient to determine that a drowning is occurring; it is only through a conjunction of several behaviors, coupled with a decision process, that drowning can be recognized.

Pia (1974) identified some of what the lifeguarding community considers important features of drowning. For example, the so-called 'instinctive drowning response' is indicated by a patron struggling for air at the water's surface—excessive action (flailing arms) without locomotion through the water—yet drowning occurs in other ways. Passive drowning, by contrast, is characterized by a lack of both action and locomotion in a body that could be at or below the surface. Some lifeguard professionals, however, question this rigid definition of drowning, and it is not clear whether these are the only features lifeguards use. Moreover, these behaviors are poor definitions for visual targets because they are not exclusive to drowning or distress. They overlap considerably with behaviors exhibited by playing children—arm motion, splashing, submersion, etc. An effective lifeguard needs to be able to quickly distinguish flailing arms in drowning from those in play, and this similarity may make identifying drowning and distress that much harder. Because lifeguards also must search for dangerous behaviors, several sets of non-exclusive features are required to complete this task.

The ill-defined nature of the search targets, coupled with their non-exclusive features, makes search difficult. In a typical visual search task, participants are instructed about and often shown an example of the target stimulus. This top–down knowledge of the target stimulus can help participants set up an attentional template (e.g., Duncan & Humphreys, 1989). An attentional template is a high-level flexible representation that can help guide search via the selection of relevant features in the environment that match those features in the template. Having an attentional template may help improve the efficiency of search via a number of different mechanisms, including but not limited to increasing the signal to a relevant attribute, rejecting stimuli without a relevant attribute as noise, or enhancing processing to a particular location or object (e.g., Desimone & Duncan, 1995; Eckstein, Abbey, Pham, & Shimozaki, 2004; Lu & Dosher, 1998; Moran & Desimone, 1985). A number of studies have begun to investigate the consequences of task constraints that inhibit or delay setting an attentional template (e.g., Treisman, 1988; Vickery, King, & Jiang, 2005; Wolfe, Butcher, Lee, & Hyle, 2003), that is, an examination of what happens to search efficiency when a search target is not well defined.

Uncertainty about target features, which can be created in the lab by varying the target across trials, slows search (e.g., Schneider & Shiffrin, 1977). For example, Treisman (1988) found that response times (RTs) to report the target were faster when it was always red among green items, compared with when the target was sometimes green among red items. Eimer, Kiss, and Nicholas (2011) extended this work using event related potentials to index spatial attention and found that increasing the number of targets decreased the efficiency of search via slowed deployment of attention to the target location and more interference from related distractors. These findings have serious consequences for lifeguards as they do not have one set of unique, discrete, or exclusive features for their search. They need to monitor the water flexibly so any attentional template would need to be complex (contain multiple features) and broadly defined, most certainly reducing search efficiency. Alternatively, if the attentional template could not be constructed to accommodate all features, attempting to change the relevant features in the template repeatedly during surveillance would also reduce efficiency (e.g., Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004).

Dynamic stimuli requiring continually maintained and updated representations

Another aspect of lifeguarding that presents a challenge in terms of vision and visual attention is that the relevant stimuli in the lifeguard's search task are dynamic, a trait not present in most laboratory studies. A static view of a swimmer will not conclusively indicate drowning or distress. Only an evaluation of behavior as it changes over time will enable a lifeguard to detect drowning and distress. Technically, a lifeguard's targets are visual *events*, rather than visual *stimuli*. There are three particular challenges that emerge because of the dynamic nature of this task.

First, the swimming activity of each patron must be monitored over time to determine when a behavior is abnormal and potentially problematic. This requires maintaining representations for all patrons (especially at-risk ones) and/or behaviors for some period of time and being able to compare current representations with previous ones. The cognitive systems that would support these tasks, visual short-term memory and working memory, have severe capacity limitations demonstrated to be approximately four items and between five and nine items, respectively (see Cowan, 2001; Gobet & Clarkson, 2004; Luck & Vogel, 1997; Miller, 1956). Additionally, each of these cognitive systems retains information for a very limited duration in the absence of active maintenance strategies. Moreover, search processes are negatively affected by high memory loads (Solman, Cheyne, & Smilek, 2011). It seems likely that maintaining representations of all patrons and/or risky behaviors for even a short period of time will exceed these limits. It is possible (and perhaps necessary) that lifeguards rely on their long-term memory to assist them with their search task; long-term memory capacity is greater, and its duration is longer. The problem, however, is that visual representations held in these stores rely on gist (e.g., Irwin & Andrews, 1996; Melcher, 2006), which is likely to be particularly problematic in lifeguarding because many of the target behaviors are similar to non-target behaviors, necessitating finer analysis.

Second, research documenting search asymmetries indicates that searching for a static figure (such as one who has lost consciousness) among several moving ones will be slow and difficult (see Wolfe, 1998b). Specifically, research by Ivry and Cohen (1992) found that targets that were moving faster than surrounding distractors were located more quickly and efficiently than targets that were moving slower than surrounding distractors. This result and others like it have been used to claim that moving stimuli are salient and therefore processed efficiently regardless of the number of distractors (e.g., Treisman & Souther, 1985; Wolfe, 2007). This means that effortfully attending to an individual or a small group may be required to locate drowning, especially if it is non-salient.

Third, an inherent problem in dynamic scenes is the changing of information present in the scene, which can happen quite rapidly. This requires continually updating internal representations of those stimuli, which is also subject to a number of limitations (see Enns, Lleras, & Moore, 2010, for a review). In particular, the visual system is faced with a particular scene and must internally represent that scene in order for the observer to attend to relevant events and act on them. As time progresses, old information from the scene is replaced with new information. This could potentially lead to a loss of critical information. A person who was visible one moment in the pool could be overwritten in the lifeguard's internal representation, without the lifeguard even realizing that he or she is gone.

Vigilance challenges

Vigilance is one's ability to focus attention and detect signals for an extended period of time under conditions where signals are intermittent, unpredictable, and infrequent. One hallmark of performance is poorer signal detection over time (the *performance decrement*; e.g., Parasuraman, 1986; Warm, Parasuraman, & Matthews, 2008). Original examinations of vigilance were conducted by Mackworth (1948; 1950) using the Clock Test, which required monitoring the movement of a pointer for a rare double-length jump. Across 30 minutes of monitoring, this target event occurred only 12 times in 20 minutes, with inter-stimulus intervals ranging from 45 seconds to 3 minutes (and a 10-minute blank period). In his experiments and other research that followed, vigilance has been shown to decrease with both heat and time on task—two factors that are clearly relevant to lifeguarding.

Heat

A meta-analysis of 22 studies conducted by Pilcher, Nadler, and Busch (2002) revealed that temperature extremes can affect several measures of cognitive performance. Exposure to temperatures in excess of 80° Fahrenheit resulted in a performance decrement of 14% in attention and perceptual tasks. The smallest performance decrements were observed in conditions where the temperature was 70°–79°. This mirrors Mackworth's (1948) work, which showed 79° to be the 'optimum' temperature. Mackworth additionally found that those who had prior experience as lookouts for the Royal Navy did not differ from novices at the lower temperatures, but at the higher temperatures, those with experience missed approximately 40% of targets, while those without experience missed between 45% and 50% of the targets. This suggests that those without extensive surveillance experience are particularly susceptible to having their performance decline as a function of temperature.

The application of this work to lifeguarding is clear: people swim when it is hot. Although many lifeguards work year-round in indoor facilities that are temperature-controlled, many others work at seasonal facilities during the summer (79% in Griffiths, Vogelsong, & Steel, 2000) or at year-round facilities in the tropics. It is not uncommon in many areas of the world to see temperatures higher than 80°, where performance decrements are likely to be observed. It is possible that the elevated temperature negatively affects lifeguard vigilance, and this could be contributing to surveillance problems in lifeguards.

Time on task

Other research has investigated how vigilance decreases as a function of time on task. Easterman, Reagan, Liu, Turner, and DeGutis (2014) determined that over the course of a continuous-performance task lasting only 10 minutes, sensitivity decreased and response time variability increased. The addition of rewards—a promise of money or early termination of the study based on accurate performance—improved task accuracy overall but did not mitigate the performance decrement.

One explanation for the vigilance decrement is resource depletion—as time on task increases, limited cognitive resources are expended and sensitivity decreases. One potential remedy for this is providing rest periods. Inserting a 1-minute break after 20 minutes of a difficult line-discrimination task did improve sensitivity slightly, but an additional break 10 minutes later did not provide further benefits (Ross, Russell, & Helton, 2014). Possibly, the 1-minute break was insufficient to replenish the cognitive resources required to complete the task.

The results of these studies suggest that lifeguard surveillance could possibly be improved if lifeguards are given frequent breaks. Requiring lifeguards to be vigilant over an assigned zone of the water for longer than 20 minutes will increase the likelihood of a missed drowning. Fortunately, the lifeguard community is aware of these limits (see Griffiths, 2002), and many facilities require that lifeguards rotate positions every 20–30 minutes to reduce boredom and increase vigilance.

Performance feedback

Schwebel, Lindsay, and Simpson (2007) presented a group of lifeguards with a brief intervention that included feedback about their collective performance. This feedback was generated from an observational study by Schwebel, Simpson, and Lindsay (2007), which found that an average of 90 dangerous events occurred every hour, and lifeguards only warned patrons once for every 14 occurrences. In addition, lifeguards were found to be distracted (their eyes and/or head were focused outside their assigned zone for at least 5 seconds) 10 times per hour on average. Although this is a crude assessment of effectiveness, it suggests that performance decrements, which may be caused by such factors as inattention, fatigue, or reduced vigilance, occur in the field even under conditions where lifeguards rotate positions. In addition to feedback about their performance, lifeguards were told of a fatal drowning that had occurred at a similar facility, highlighting the severity of the drowning risk, and were given a reminder of the scan paths they had been taught to use during training. After this intervention, distraction was reduced and dangerous behaviors decreased.

Feedback about insufficient scanning helped the lifeguards in the study by Schwebel, Lindsay, and Simpson (2007), suggesting that feedback may be crucial to keeping lifeguards performing optimally. What function might feedback serve? Historically, the performance decrement observed during vigilance tasks was attributed to such factors as decline in arousal and boredom because the tasks are understimulating (Parasuraman, 1984). Inserting a non-specific motivational message to ‘do even better’ into Mackworth’s (1948) vigilance task increased detection by nearly 20%, which lends some support to a boredom explanation. But research studies show converging evidence across behavioral, neural, and subjective measures that vigilance tasks are *not* boring; they place substantial demands on cognitive processing resources and are not simply due to a lack of motivation (e.g., Easterman et al., 2014; Warm et al., 2008). In fact, Easterman et al. (2014) found no difference in the vigilance decrement when feedback was periodically provided and when it was not. This is contrary to the idea that target misses are due to participants ‘zoning out’ or becoming disengaged in the task.

DISTINGUISHING LIFEGUARD SURVEILLANCE FROM TRADITIONAL LABORATORY RESEARCH

Visual search versus visual surveillance

Although the lifeguard’s surveillance task can be characterized as visual search, which has been extensively studied in recent decades (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe, 1998b), there are several key differences. A traditional laboratory visual search task requires *spatially* locating a discrete target *object* within a *static* environment. Unlike traditional visual search tasks, lifeguarding requires continuous monitoring of a dynamic visual scene over an extended period of time, looking for what we refer to as *critical events*. Thus, surveillance requires *temporally* locating a discrete target *event* within a *dynamic* environment. Note that some laboratory studies have examined search in dynamic or changing displays (e.g., Driver & McLeod, 1992; Rensink, 2000; 2002; Von Mühlenen & Müller, 2001); however, these tasks required detecting target *objects*, not *events*. Research on event detection has revealed that human observers parse their experience into discrete events, automatically using perceptual features and task goals (Zacks & Swallow, 2007). Event boundaries are perceived when periods of change violate the observer’s ability to predict future perceptual input (see Zacks, Speer, Swallow, Braver, & Reynolds, 2007). This suggests that lifeguards are probably parsing their visual input into discrete events, but research has not yet combined event detection with visual search in a way that will inform lifeguard surveillance theory.

Ecological validity

Traditional laboratory search tasks typically lack ecological validity. Many search tasks use simple shapes or letter stimuli, although attempts have been made to use more ‘real-world’ stimuli such as rendered three-dimensional visual scenes (e.g., Irwin & Zelinsky, 2002; Oliva, Wolfe, & Arsenio, 2004), photographs of natural scenes (e.g., Itti, Koch, & Niebur, 1998; Parkhurst & Niebur, 2003), images from airport security scanners (e.g., Van Wert, Horowitz, & Wolfe, 2009; Wolfe et al., 2007), and medical images (e.g., Jiang, Miglioretti, Metz, & Schmidt, 2007; Krupinski, 1996).

Laboratory studies also cannot totally replicate the motivation that might exist in the field. A missed target for a volunteer in an experiment is not nearly as consequential as a missed drowning for a lifeguard. Attempts to motivate participants in laboratory search tasks by offering points (e.g., Wolfe et al., 2005) or even money (Clark, Cain, Adcock, & Mitroff, 2011; Pedersini, Van Wert, Horowitz, & Wolfe, 2008) for accurate performance may not fully replicate the motivation experienced by professionals in the field and often show little effect on performance.

Development of automatization with expertise

Most laboratory studies of visual search rely on novice observers, and because most search tasks involve simple stimuli, a short practice session is sufficient to ensure stable search performance. With complex stimuli, the search is more difficult and requires a greater level of expertise to perform well. A novice might have to perform an effortful, active search, devoting most of their cognitive resources to the perception and evaluation of patron behaviors. Developing expertise may promote increased automatization and decreased controlled processing in many of the cognitive procedures required to perform this task (e.g., Shiffrin & Schneider, 1977), producing a search that seems to the observer to be more passive.

Lifeguard training manuals often imply if not state outright that surveillance is to be an active and controlled process. For example, the most recent version of the Red Cross training manual instructs readers that scanning is

> … an active process. When scanning, a lifeguard should not just passively watch patrons in the water. The lifeguard should actively observe the swimmers' behaviors and look for signals that someone in the water needs help. The lifeguard's head needs to move while scanning to look directly at each area rather than staring in a fixed direction. Movement may be noticed with peripheral (side) vision, but recognition requires looking directly at the person. … Scan from point to point, rapidly watching all movements of the patrons in the area. (American Red Cross, 2007, p. 31)

Yet, one lifeguard offered the following account of surveillance in an interview with one of the authors (CMM), 'I try to watch the whole zone and make sure there isn't any weird stuff happening.' This description is strikingly similar to the passive search process studied by Smilek, Dixon, and Merikle (2006) and Smilek, Enns, Eastwood, and Merikle (2006). To use a passive search, participants are instructed to simply let the target item (a unique object in the display) 'pop' into their minds and use their 'intuition' to determine their response of target presence or absence. In this paradigm, passive search was more efficient (less affected by set size) than active search for a difficult target, although not for an easier target (Smilek, Dixon, *et al.*, 2006; Smilek, Enns, *et al.*, 2006). Despite these results, it is unclear whether this strategy would be effective in a surveillance task like lifeguarding. Passive search is accompanied by fewer saccades but a longer delay in saccade initiation, whereas active search is accompanied by more saccades that are quicker (Watson, Brennen, Kingstone, & Enns, 2010). Additionally, a passive strategy is better for a computer-based search task, but an active strategy is better for search for a real object in a real scene (Brennan, Watson, Kingstone, & Enns, 2011). Because lifeguards are searching for real objects and must search through several of them, initiating many quick saccades is going to be critical to their success. This would suggest that an active search should be superior to a passive one, although this does not take into account the effect of expertise and the potential automatization of perceptual evaluative processes.

The studies earlier used novice volunteer participants who had limited exposure to these visual stimuli. A typical lifeguard who works even one summer will amass hundreds of hours of visual experience. Perceptual learning occurs in most tasks that are performed repeatedly (e.g., Shore & Klein, 2000). As expertise increases, there is improved sensitivity or tuning to the perceptual features that can help boost performance and simultaneously reduce sensitivity to irrelevant features; both aspects are critical for optimizing discrimination (e.g., Goldstone, 1998; Shore & Klein, 2000). Familiarity with relevant search items can also help perceptually organize a degraded display (e.g., Peterson & Gibson, 1994). This learning can be both task and item/object specific, and the specificity of this learning varies with difficulty of the task, such that training on easy tasks allows transfer of learning to a wider range of tasks than training on difficult tasks (e.g., Goldstone, 1998; Shore & Klein, 2000).

A great deal of research has evaluated the difference between search behaviors of novices and experts, particularly in fields such as radiology. Expert radiologists find their target faster, more efficiently, and with greater accuracy (e.g., Crowley, Naus, Stewart, & Friedman, 2003; Drew, Evans, Võ, Jacobson, & Wolfe, 2013; Krupinski, 2000; Nodine et al., 1999). Eye movement monitoring has revealed more efficient scan paths for experts compared with novices (Krupinski, Graham, & Weinstein, 2013). Furthermore, this advantage only comes with repeated exposure to particular images, not to a more generalized search task, implying that the expert advantage arises from perceptual tuning, rather than an individual predisposition for such tasks (e.g., Nodine & Mello-Thoms, 2010). Expert radiologists often comment that they had a sensation of 'knowing' an abnormality was present prior to detection (Drew et al., 2013).

Although these studies involved tasks with higher-prevalence targets and more performance feedback, they suggest that as observers gain experience, they should be able to find drowning incidents faster and more accurately and rely on more efficient search processes. Theoretically, they should be more sensitive to the features associated with drowning, distress, and dangerous behavior and less sensitive to other behaviors. The problem, as described earlier, is that the behaviors that are diagnostic of drowning, distress, and dangerous behavior are not unique and exclusive. Therefore, the perceptual tuning may not be as effective as it would be in a traditional search task. There is also some evidence to suggest that lifeguards as a group are relatively inexperienced—Griffiths et al. (2000) found in a survey of 10,000 North American and Australia/New Zealand lifeguards that 52% were under the age of 20 years, 52% had fewer than 12 months of work experience, and only 21% were career lifeguards as opposed to seasonal ones. These conditions make it very difficult to generalize from other occupations such as radiology, whose practitioners are often more experienced.

ADAPTING LABORATORY METHODS TO STUDY LIFEGUARD SURVEILLANCE

In order to study lifeguard surveillance, or surveillance in general, traditional laboratory methods of examining visual search need to be modified in order to replicate most accurately as many of the features of the task as possible. Mackworth's (1948; 1950) Clock Test was an initial attempt to examine surveillance by requiring observers to respond to a temporal event (a double-length pointer jump), and others have developed continuous-performance tasks (e.g., Easterman et al., 2014) that similarly require continuous monitoring of input for prescribed targets, but there are other ways that surveillance can be studied using simple modifications to existing search tasks.

Search tasks with dynamic properties

In a traditional search task, a static display is presented and participants are usually asked to either report some changing feature of the target (e.g., report the left–right facing direction of an arrow) or simply indicate its presence or absence. The simplest modification that can be made to this task is to insert some dynamic properties into the display. For example, participants could be asked to accomplish a basic visual search task, such as reporting the tilt of an oblique bar among vertical and horizontal line segments. The search is given a dynamic context by embedding the target display within a movie of other displays where the bars are rotating in 10° steps through different orientations. The target display, which is the only one to present a single oblique target among vertical and horizontal bar distractors, is presented in the middle of this series of displays. In the other displays, all the items are oblique. Therefore, successful performance in the task requires that participants extract the correct oblique bar, which can only be done by isolating the target display where all the distractors are horizontal and vertical bars. The context of the task becomes event based, thereby translating the visual search task so that it better approximates a surveillance task while still allowing a comparison of the results to those that might be obtained in a traditional search task.

In the traditional static task, detecting the target is very easy; it pops out. However, preliminary data from an experiment like the one described show evidence that participants have a very difficult time extracting the target from among these dynamic displays (e.g., Jardine & Moore, 2012; Moore, Skow, Lanagan-Leitzel, & Attarha, 2011). The results thus far are consistent with the hypothesis that the poor performance in surveillance reflects representational updating, such that the instantaneous state of the target frame is inaccessible because the visual system has already sampled a new display and changed the previous representation.

Define the target as an event

Embedding the target display in a dynamic context is a good first step, but a necessary further extension involves defining the target itself as an event. For example, a target could be defined by a particular series of changes that unfold over time (e.g., a line that flips back and forth between 0° and 45° over a series of frames). This is similar to a lifeguard watching for not just a child who has dived underwater but a child who has dived underwater and failed to surface within a reasonable period of time. The event context could be other bars that are rotating, some of which will attain 45° and then move to 0°, but not back again, and other bars that will toggle back and forth between non-45° angles for the requisite amount of time. Therefore, in this paradigm, both the target and search context would be event based, completing the adaptation from a search task into a surveillance task. The problem is that simply extracting the critical item from the dynamic search context described earlier is difficult enough; requiring participants to isolate a particular pattern of dynamic activity within that dynamic context may be completely impossible.

Using variable-onset targets

A third approach could explore how objects within a dynamic scene are represented as they move into and out of view. This question arises solely because of the event context of surveillance tasks. For example, consider swimmers in a pool: not only can swimmers enter and exit the water, but they might also swim into and out of the lifeguard's coverage zone. The observer's representation of the scene must allow for the addition of new patrons and, at least for some period of time, continue to include those patrons that have exited but may return. How long do those representations remain intact?

Because of the dynamic nature of a surveillance task, one must account for temporal variability in the onset of the target and thus integration of information across time. This is very unlike static visual search tasks in which the target is either present or absent from the start of the display presentation. What happens to observer efficiency and accuracy when the onset of the target is not predictable? The change blindness paradigm can be modified to serve this purpose (e.g., Skow & Moore, 2012). Observers see fields of vertical and horizontal bars that flash on and off the monitor (with an interleaving blank screen that disrupts processing). This sequence cycles continuously for the duration of a trial. The task is to find a single bar that alternates between vertical and horizontal among distractor bars that always maintain a constant orientation. Critically, the target bars onset (switch to a vertical and horizontal orientation) after a variable length of time. Preliminary data suggest that previewing the visual display for up to 12 seconds speeds performance. Additional experiments could be conducted to investigate what aspect of the preview is helpful to performance (e.g., spatial-based vs. identity-based information).

Using video stimuli

Finally, it is necessary to consider using real-world stimuli to study real-world surveillance tasks. Earlier work exploring the visual limitations in lifeguarding (Lanagan-Leitzel, 2012; Lanagan-Leitzel & Moore, 2010) used stimuli that consisted of video-taped swimming venues. Lifeguard participants looked at few critical events (Lanagan-Leitzel & Moore, 2010), most likely because there is considerable variability in which events are reported by lifeguards to be critical (Lanagan-Leitzel, 2012). A serious flaw with these videos, however, is that they contained only normal swimming activity. Although there were many dangerous behaviors and some potential drowning risks, there were no actual drowning or distress incidents on the days of filming. Therefore, there was no objective target that could be used to evaluate the effectiveness or attentiveness of these lifeguard participants. It is difficult to capture a real drowning incident on video, and if facilities capture these incidents on surveillance cameras, they are kept private. Nevertheless, critical events—events that lifeguards should monitor because of the potential for danger they pose—occur frequently in the field. We are currently in the process of developing a library of video from several swimming venues that contain these events, and each video will be coded and validated for these critical events. This will provide a much richer, more varied, and better-understood stimulus set with which to conduct controlled laboratory experiments.

THE IMPORTANCE OF APPLIED RESEARCH

Basic research has yielded insight into many fundamental perceptual processes and behaviors. Applied research allows researchers to examine real-world problems creatively to solve an existing problem. When cell phones became popular, Strayer, Drews, and Johnston (2003) used a driving simulator to demonstrate that conversing on them leads to several measurable declines in driving performance (even on hands-free devices, which are still allowed by law in many states). Atkins, Moise, and Rohling (2006) were able to develop and test a new workstation navigation technique for radiologists designed to simplify their duties. Airport security screening has also recently enjoyed a great deal of focus within the visual cognition literature (Fleck & Mitroff, 2007; Godwin, Menneer, Cave, & Donnelly, 2010; Van Wert et al., 2009; Wolfe et al., 2005; Wolfe et al., 2007; Wolfe & Van Wert, 2010), as well as cytology (Evans et al., 2011). These studies have not only contributed to growing knowledge on human information processing, but they also have offered ways to improve job performance for radiologists and baggage screeners.

Lifeguarding has just begun to be examined within the laboratory (Lanagan-Leitzel, 2012; Lanagan-Leitzel & Moore, 2010). Examining real-world search tasks such as lifeguarding can be inherently difficult, as they often are far more complex than can be reliably replicated in a laboratory. These tasks can also often fail to replicate the motivational state a lifeguard may have when a patron's life is really at risk. Yet, attempting to study lifeguarding and other surveillance tasks confers many benefits. The results will likely provide additional insight into complex perceptual processes that can be further explored through basic research.

CONCLUSIONS

The visual cognition and attention literature reviewed here presents a stunning picture of the processing limitations that are endured by lifeguards each time they work. Lifeguards must remain vigilant in their search for a target that is complex, dynamic, and ill-defined in an environment that is visually noisy, cluttered, and full of the individual features present in that target. Attentional limitations further make this vigilance difficult—increased temperatures, when people are most likely to swim, decrease vigilance (Easterman et al., 2014), and repeated identifications of non-drowning dangerous events (Fleck et al., 2010) such as horseplay could detract from other events in the water, potentially leading to missed drowning events (Mack & Rock, 1998; Rensink, 2000; 2002; Simons & Rensink, 2005). With all these limitations, it is important to consider what is contributing to lifeguard success. Although we have proposed that one mechanism underlying this success is automatization of perceptual evaluative processes that arise with developed visual expertise, this idea warrants further investigation by our field. It is with the systematic study of search afforded by the laboratory that the current rescue rate can be improved as we explore how lifeguards are able to overcome their limitations and satisfy society's great expectations.

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