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Cognition and lifeguard detection performance

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Abstract

Two experiments aimed to determine whether working memory capacity (WMC) and high-order executive functions predict drown detection performance and maintenance under heightened task demands. Experiment 1 ($n = 111$) found a positive correlation between enhanced performance scores and higher WMC, while executive function showed no comparable association. Experiment 2 ($n = 28$) individuals with elevated WMC demonstrated an ability to detect a greater number of drowning events over an extended period overall, relative to their lower scoring counterparts. However, this heightened capacity did not necessarily prevent the presence of vigilance decrement, but enabled lifeguards to perform more effectively under conditions of increased bather numbers. Our findings highlight that lifeguards have a measurable underlying process that may systematically discriminate lifeguards of varying degrees of experience and detection performance. This offers a new avenue for future lifeguarding research.

KEYWORDS
drown detection, executive function, vigilance, working memory capacity

1 | INTRODUCTION

A lifeguard's principal responsibility involves the vigilant oversight of bathers, ready to respond should a drowning event, hazard, or accident transpire on a poolside or beach (Hunsucker & Davison, 2008; Lanagan-Leitzel, 2012; Petrass & Blitvich, 2014) necessitating sustained attentiveness over prolonged time frames (Schwebel et al., 2011). Existing literature has underscored the challenges inexperienced individuals face when tasked with activities that demand the discernment and assimilation of pertinent information, the integration of prior knowledge, and the adept selection of appropriate responses (Marteniuk, 1976). Such challenges are notably pronounced within lifeguarding settings, where the bather count is variable (Lanagan-Leitzel, 2021; Vansteenkiste et al., 2021), and the duration of a drowning event remains unpredictable (Carballo-Fazanes et al., 2020).

The ability to continuously process stimuli, such as the presence of bathers, while simultaneously striving to identify specific signals, like a drowning incident, characterizes a vigilance task (Davies & Parasuraman, 1982). Instances of diminished performance during extended monitoring tasks have been recurrently observed (Killingsworth & Gilbert, 2010), particularly within lifeguarding duties that demand a heightened cognitive load (Sharpe et al., 2023). As such, gaining insights into the mechanisms underpinning effective lifeguard performance holds the potential to facilitate the refinement of drowning detection training methodologies. Consequently, this endeavour may then contribute to the reduction in drowning events unfolding in zones overseen by trained lifeguards.

Interestingly, cognition plays a critical role in an individual's ability to direct conscious focus in a highly distracting environment (Conway & Kane, 2001), sustain attention during vigilance tasks

(Unsworth et al., 2020; Unsworth & Robison, 2017), inhibit task-irrelevant information (Furley & Wood, 2016; Kane & Engle, 2003), resist mind-wandering (Robison et al., 2017, 2020), anticipate changing situations (Verburgh et al., 2014), and make more effective decisions (Vaughan & Edwards, 2020; Vaughan & Laborde, 2021). These key processes inherently influence a lifeguard's ability to perform their role (Hunsucker & Davison, 2008). Considering the reported critical nature of cognition on performance, the current study aims to explore the relationship between components of cognition and detection performance within a lifeguard population. Cognitive mechanisms that allow for individuals to regulate lower-level processes (e.g., perception) and self-directed behaviours toward a goal have been associated with components of executive function (Friedman et al., 2016; Miyake et al., 2000) and working memory capacity (Engle, 2002; Unsworth & Engle, 2007). Executive functions are typically considered a set of higher-order cognitive process that govern goal-directed action and adaptive responses under conditions of novelty, distraction, and conflicting task demands (Hughes et al., 2005), whilst WMC is considered a mechanism responsible for retaining a small amount of information in an active state for use in ongoing tasks (Baddeley, 2007; Miyake & Shah, 1999). These mechanisms have been associated with the prefrontal cortex and associated structures, such as the thalamus, involving controlled and automatic processing (Kane & Engle, 2002; Picton et al., 2006) with high cognitive abilities being consistently associated with performance (Furley & Memmert, 2012; Jacobson & Matthaeus, 2014; Vaughan & Edwards, 2020; Wood et al., 2016), particularly with monitoring tasks that require a control of attention over prolonged periods (Unsworth & Robison, 2017, 2020).

Given the reported associations with cognition (i.e., general reasoning, problem solving, achievement; Engle et al., 1999; Miyake & Shah, 1999), and the increase in interventions exploring the transfer effects of cognitive training on performance (Kassai et al., 2019; Owen et al., 2010), it is surprising that to date lifeguard research remains limited to visual search. Particularly, given that considerable evidence has demonstrated various components of cognition significantly contribute towards tasks that are reflective of the most critical role of a lifeguard; that is, an ability to remain acutely attentive towards bathers over an extended period (Schwebel et al., 2011). Indeed, there has been growing interest in determining the individual differences associated with lifeguard experience (Lanagan-Leitzel, 2012; Laxton et al., 2022; Laxton, Crundall, et al., 2021; Laxton, Guest, et al., 2021; Page et al., 2011). For example, visual search research has demonstrated that experienced lifeguards are superior hazard detectors compared to in-experienced lifeguards (Laxton, Crundall, et al., 2021; Page et al., 2011). Investigations have reported experienced beach lifeguards as 4.9 times more likely to detect a drown victim than less experienced groups (Page et al., 2011) and have faster response times to drown scenarios (Laxton, Crundall, et al., 2021). However, the detection rates of groups appear to not be underpinned by systematic differences in visual search patterns. Research has yet to determine what discriminates these performance differences associated with higher durations of lifeguarding employment. Hence, recent literature has called for such cognitive investigation to help the field understand why lifeguards of varying degrees of experience consistently demonstrate performance differences (Laxton et al., 2022; Sharpe et al., 2023; Smith et al., 2020) and perhaps determine a means to improve the detection performance of newly qualified lifeguards quickly (Laxton et al., 2023).

2 | EXPERIMENT 1

Experiment 1 aimed to determine the relationship between executive function and working memory capacity on target detection performance amongst lifeguards. Given the reported association between cognition and performance (Furley & Memmert, 2012; Wood et al., 2016), particularly during vigilance tasks (Unsworth et al., 2020; Unsworth & Robison, 2020; Verburgh et al., 2014), the experiment hypothesised that WMC and executive function will be positively associated with drown detection performance. Further, as literature suggests experienced lifeguards are superior hazard detectors compared to in-experienced lifeguards (Lanagan-Leitzel & Moore, 2010; Page et al., 2011), our study predicted the most experienced lifeguards would hold the greatest advantage in detection ability.

3 | METHODS

3.1 | Participants

A total of 111 current or previously certified lifeguards ($M_{\text{age}} = 24.51$, $SD = 5.66$ years), with varying durations of employment in months ($M_{\text{lifeguard employment}} = 54.19$, $SD = 67.79$ months) participated in the study. G*Power 3.1.9.4 software (Faul et al., 2007) was used to perform an a priori calculation of sample size based on the formula proposed by Faul and colleagues (Faul et al., 2009). With a power (1-β) of .80, two-tailed α of .05 and the set of predictors, 108 participants were required to detect a medium effect ($f^2 = .15$). The sample consisted of 36 females and 75 males, from a range of lifeguard professions, including: recreational pool ($n = 45$); competitive pool ($n = 4$); private pool ($n = 6$); public beach ($n = 23$); private beach ($n = 21$); and surf beach lifeguards ($n = 12$). The data for this portion of the study was collected during a period of seven months. Ethical approval for the study protocol was awarded by the lead Universities research ethics committee. All participants provided informed consent through the initial section of the online battery.

3.2 | Experimental tasks

3.2.1 | Executive function

Switching stroop

A variant of the Stroop test (Stroop, 1935) was used to assess an individual's ability to direct attention to select certain responses while intentionally inhibiting others. More specifically, the Switching Stroop Task examined the capacity to avoid distraction through planning the allocation of attention towards a specific stimulus and was adopted as a measure of inhibition (Karr et al., 2018). The top of the screen presented the prompt (e.g., 'Ink' or 'Text'). The stimuli, presented in the centre of the screen, is a colour block (e.g., red). On either side of the stimuli the options (e.g., RED and YELLOW) were presented. The participant's task was to determine which option describes the colour block, dependent on the prompt option provided. Colour-word mappings were congruent or incongruent. Success was recorded by a single point gain for each round, whilst error resulted in a point deduction. The task ended after 90 s. The outcome measure was the total score (all subsequent cognitive tasks present a single total score).

Tower of london

An online version of the of the tower of London task (Shallice, 1988) was used to assess an individual's ability to identify and maintain goals whilst evaluating the sequence of operations required to solve the task (Polk et al., 2002). The task has been successfully utilised to record functions of planning and problem solving (Kaller et al., 2008), and has been previously adopted to assess the inhibitory component of executive functioning (Wiebe et al., 2008). For this task participants were presented with two sets of pegs with colour blocks on them. The first image had the original location of coloured blocks whilst the second image has an adjusted order of coloured blocks. To be successful, individuals had to calculate the minimum number of moves (e.g., moving one block equals a single move) that would be required to get from image one to image two. Difficulty was automatically adjusted dependant on the individual, with success resulting in images increasing in complexity. The test ended after 3 min or once 3 errors were conceived.

Feature match

An online variant of the classic feature search tasks used to measure attentional processing (Treisman & Gelade, 1980). The task is a perceptual test that requires the individual to shift attention towards two similar sets of shapes. Requiring an ability to draw relationships between identical, disparate, and dissimilar phenomena (i.e., reasoning ability), the task has been used to record an individual's ability to selectively direct and adapt attention (Hampshire et al., 2009). One patterned grid appears at the top of the screen and four similar patterned grids of abstract shapes appear below. The individual had to click on the pattern in an exact replication of the above pattern. Patterns alter by just one shape in half of the trials and alter throughout the duration of the task. Success was recorded on a point system (i.e., total score increases by the number of shapes in the grid) and for every correct response the number of shapes in subsequent trials increases. The task ended after 2 min.

2D manipulation task (i.e., spatial rotation)

Used for measuring the ability to manipulate objects spatially in the mind (Silverman et al., 2000). Like Feature Match, the task is a perceptual test that requires an individual to successfully direct attention towards two similar sets of shapes. The key difference concerns a function of mental rotation (i.e., the ability to manipulate bidimensional stimuli to match one another), which requires the individual to draw relationships between objects that have been rotated (Linn & Petersen, 1985). The design and scoring of the task were identical to the previous task, the differences solely concern the four similar patterned grids of abstract shapes being rotated. Success was recorded through an individual's ability to identify the rotated pattern that is an exact replication of the above pattern. The task ended after 3 min.

Block rearrange

Commonly referred to as a spatial visualisation task (Carroll, 1993), was employed. Block Rearrange is an adapted task from a common analogue neuropsychological test in which the participant must match a shape using coloured blocks. The task closely resembled the core executive function of updating (i.e., continuously adjusting conceptual information from moment to moment), as the individual must hold information between tasks to successfully predict the shapes that will be created once an action is performed (C. A. Cohen & Hegarty, 2007). The task involved two separate square grids, one of which includes a series of coloured blocks of differencing shapes (interactive) and the other presents a fixed block with missing sections (goal). It was the participants role to remove the shapes from the interactive task and replicate the goal image. The difficulty was extended by a gravity effect (i.e., removing a shape will cause the above shapes to collapse if not supported) and hence the task relied on an individual's planning ability to predict the shapes that will be created once a block is removed. Success was recorded by a single point gain for each round, whilst error resulted in a point deduction. The task consisted of 15 rounds, typically lasting 3 min.

Verbal reasoning

Based on Alan Baddeley's 3-min grammatical reasoning test (Baddeley, 1968), requiring the ability to filter out key information from a bulk of text. The task required an ability to monitor and code incoming information and update no longer relevant information with information relevant to the task (Baddeley, 1968). Specifically, the task asked the participants numerous TRUE or FALSE statements regarding the visual image presented (e.g., a circle within a box). The screen displayed a statement that was deciphered by the participants (e.g., "The square is not encapsulated by the circle"). Success was dependent on the number of accurate responses provided by the individual. Success was recorded by a single point gain for each round, whilst error will result in a point deduction. The task concluded after 2 min.

3.2.2 | Working memory capacity

The spatial span task

Based on the Corsi Block Tapping Task (Corsi, 1972), used to assess spatial short-term memory capacity. A task thought to measure an individual's ability to remember visually presented spatial information during a short period of time. The task, and those similar, have been implemented in conjunction with other working memory tasks to measure working memory capacity (Lee et al., 2007; Metzler-Baddeley et al., 2017; St Clair-Thompson & Gathercole, 2006). Displayed in a 4 * 4 grid, 16 squares were presented and then flashed (1 flash every 900 ms) in a random sequence. The task required the participant to repeat the sequence by clicking on the squares in the order to which they flashed. Difficulty began from four flashes per round and dynamically varied based on success rate (e.g., one successful round of four flashes progressed to five flashes in the next round). The test concluded after 3 errors.

Forward and backward digit span

A computerised variant of the verbal working memory component of the WAIS-R intelligence test (Wechsler, 1981), was then administered. Forward recall provides a measurement of basic storage capacity of the phonological loop, whereas backward recall, requiring storage and manipulation of the information prior to recall, is thought to exercise visuospatial short-term working memory. Such tasks have been adopted, collectively or individually, to measure working memory capacity in previous literature (Lee et al., 2007; Metzler-Baddeley et al., 2017; St Clair-Thompson & Gathercole, 2006). Sharing similarity to the Corsi Block Tapping task, participants viewed a sequence of digits that appear on the screen one after another. Participants made to remember the linear or reversed sequence of digits observed to complete the task. Difficulty was dynamically varied, each round a digit was added or removed dependant on previous success. The test ended after 3 errors.

3.3 | Drown detection performance task

3.3.1 | Bobbing along

A lifeguard specific drown detection tool that simulates the maximum vigilance task presented to a certified lifeguard (Sharpe et al., 2023). The task was designed utilizing Unreal Engine 4 (UE4), employing custom C++ code to establish the necessary functionality for a conventional paradigm task. Additionally, built-in blueprints were utilized to streamline the creation and monitoring of the 3D environment (Hill, 2021). The environment itself is segmented into 16 navigation meshes, wherein two actors (‘bathers’) per mesh adhere to an AI routine. These actors navigate (‘swim’) randomly within the mesh. In the event of a ‘drowning’ occurrence, the designated ‘bather’ assumes a treading-water stance and gradually submerges over a span of 30 s (as depicted in Figure 1). Throughout the 60-min task duration, there were no instances of restarting, pausing, or resetting bather positions. Following complete submersion, the bathers resurfaced after a 10-second interval and resume their randomized swim pattern. Consistently across all participants, the swim patterns, drowning locations, and timings for drown events were identical. The task's continuous nature was designed to emulate the real-world responsibilities of a lifeguard, mirroring their obligation to survey all bathers within an aquatic setting. This design aligns with the recommendations of the Royal Life Saving Society (RLSS UK), which suggests a task duration of up to a maximum of sixty minutes (RLSS, 2017). The authors would like to acknowledge that the nature of the task itself may give rise to methodological concerns analogous to those deliberated upon in prior works (see Laxton et al., 2018; Page et al., 2011). Specifically, these concerns encompass the task's potential lack of complete representativeness, including aspects such as consistent drowning durations and the frequency of drowning incidents, or the non-utilization of naturalistic footage in the current investigation. Considering the contradictory results found in various lifeguard studies as noted prior, it is suggested that there is merit in initially investigating the factors influencing lifeguard performance in controlled scenarios that might not completely mirror real-life situations but still trigger expert-level responses. This approach enhances the reliability of addressing specific research inquiries. Nonetheless, it is advised to interpret these findings with caution.

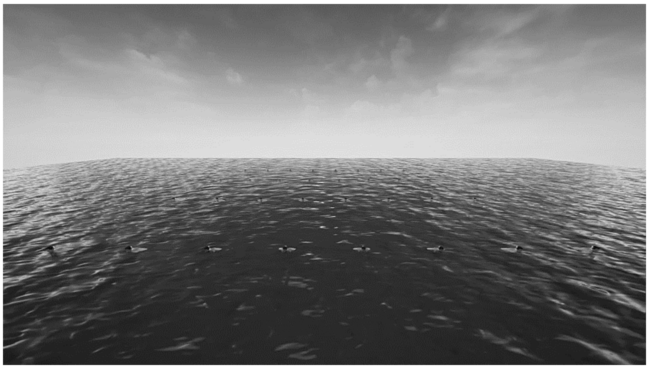

FIGURE 1 Screen capture of the Bobbing Along task with 32 bathers.

3.4 | Study design & procedure

All testing was carried out within normal working hours (7 am–5 pm). Before their laboratory visit, participants engaged in an online assessment battery designed to evaluate the demographic and cognitive proficiencies of the study's population. This battery comprised ten tasks and aimed to investigate potential connections between cognitive components among lifeguards with diverse levels of lifeguarding experience. The initial segment of the battery encompassed a demographic assessment, encompassing fundamental demographic details (e.g., age, gender) and lifeguard-specific aspects of the participant's background (e.g., duration of lifeguarding employment, specific lifeguarding roles). Nine cognitive tasks followed the demographic section, based on classical paradigms from the cognitive neuroscience literature to measure executive functioning and working memory capacity (see Experimental Tasks). Such tasks were designed and programmed by A.H. and have been utilised in previous studies (Hampshire et al., 2019, 2021; Metzler-Baddeley et al., 2017). The entire assessment battery took approximately 30 min to complete, with each task calculating one outcome measure. The tasks were presented in a fixed sequence on a secure customer server (https://lifeguard.cognitron.co.uk/). The tasks are based on a sub-sample of the Great British Intelligence Test, which has now been performed by ~0.8 million people.

Once completed, participants were invited to the laboratory to take part in the Bobbing Along task on a day of their choosing within normal working hours. Initially, a practice trial was completed to ensure participants understood the target stimuli (i.e., drown event) and could clearly see the task. Participants were asked to respond when they thought they could see a drowning event unfolding – recorded through a response clicker that provided the researcher with timings of the 'drown event'. All participants detected the drown event within the practice trial without prompting. During the main trial, participants were asked to respond if they thought they could see a drowning event unfolding – recorded through a response clicker that provided the researcher with Hit (scored as a 1) or Miss (scored as a 0). The participant was able to make multiple responses and vocalised their decisions. As each task comprised of eleven drown events, the total number of successful Hits allowed the researchers to calculate a drowning detection performance score ranging from zero to eleven. A researcher was consistently present during all testing conditions to ensure the precision of these detections, thereby preventing instances of responding to false alarms during actual drowning events. However, the tally of false alarms was not systematically recorded. The task was presented 2-meters away from the participant on a 100-inch (16:9) high definition (4 K) SAMSUNG widescreen projector via an ASUS gaming computer (GEFORCE GTX 980). The visual angle was calculated to be 64 degrees. In consideration of the central vision encompassing 30 degrees, which constitutes a fraction of the monocular visual field (Spector, 1990), the positioning of the lifeguards necessitated a minimum head movement of 15 degrees in both the left and right directions. This movement was required to effectively monitor swimmers in the lower corners of the pool, a scenario that is akin to a 25-meter pool where a lifeguard stands 2-meters away from the pool edge. From the perspective of lifeguards and dependant on bather position, the diameter of the bather's head ranged from 0.2 to 1.5 cm. Unknown to the participant, all drown events occurred at five-minute intervals in a pre-established location consisting of 11 drown events. Each participant observed an identical version of each task. Participants were unaware of the number of drown events occurring throughout the tasks. Other than the researcher, participants completed the task alone, in a quiet, and artificially lit room. The room remained darkened from natural light so that illumination could be controlled ($M_{\text{Horizonal}} = 11.34$, $SD = 3.69$ Lx; $M_{\text{Vertical}} = 42.09$, $SD = 6.11$ Lx) across all testing (recorded through the LUX LIGHT APP).

3.5 | Data analysis

Statistical analysis was carried out using IBM SPSS version 25.0 (SPSS, Inc., 2013). Data for each observed variable were screened for univariate normality using skewness and kurtosis ratios (Fallowfield et al., 2005). Skewness and kurtosis for all measures met criteria for normality (Kline, 1998) and no univariate or multivariate outliers were identified. Prior to analysis, individual item scores were standardised to allow for comparisons to be made. For remaining cognitive data, all measures were subjected to factor reduction by conducting principal component analysis. Principal component analysis (PCA) gives new variables that are linear functions of those in the original dataset, that successively maximize variance and that are uncorrelated with each other (Jolliffe & Cadima, 2016). This widely used data-led technique is used to maximize the variability and reduce the dimensionality of a dataset (e.g., Amieva et al., 2003). Such technique is valuable given the multiple structures shared by each cognitive task (Testa et al., 2012). Tasks that have been used previously to measure working memory capacity (Lee et al., 2007; Metzler-Baddeley et al., 2017; St Clair-Thompson & Gathercole, 2006), and high-order components of executive function (i.e., planning and reasoning ability; Corbett et al., 2015; Metzler-Baddeley et al., 2017). The following descriptions of these high-order components include: planning, responsible for modelling and anticipating the consequences of action before executing goals (Kaller et al., 2008; Unterrainer & Owen, 2006); and reasoning, requiring the ability to draw relationships between disparate or dissimilar phenomena, manipulate working memory and extract information from past and current information in order to achieve an outcome (Goswami et al., 1998; Krawczyk et al., 2008; Waltz et al., 1999). Given the variety of decision rules available, and the lack of consensus over the methods most appropriate for PCA (Crawford & Koopman, 1979; Hakstian et al., 1982), we utilised a four-fold approach as follows: parallel analysis (Horn, 1965), Kaiser criterion (>1; Kaiser, 1960), Cattell's scree plots were inspected (Cattell, 1952) and the interpretability of the statistical output was considered (Fabrigar et al., 1999). Orthogonal Varimax rotation was applied to the component matrix (Kaiser, 1958, 1960). Varimax rotation seeks to increase the variances of the factor loadings, resulting in both large and small factor loadings (i.e., factor loadings above 0.4 were considered significant; Howard, 2016).

Correlations were used to examine the relationships between each independent variable and the dependent variable. Experience was used as covariates in subsequent regression analysis given the plethora of research that has demonstrated the performance advantages held by lifeguards of prolonged employment (Lanagan-Leitzel & Moore, 2010; Laxton, Crundall, et al., 2021; Page et al., 2011). Hierarchical linear regression was used to assess the relative strength of independent variables in predicting each dependent variable. All data was inspected with respect to normality and linearity. For correlation and regression analysis, data did not violate assumptions of multicollinearity and normality (Tabacnick et al., 2007). All Variance Inflation Factor Values (<1.4) and Tolerance values (>0.7) were acceptable (Hair et al., 1995). The independent errors assumption was satisfied, with Durbin-Watson values between 1.5 and 1.8 (Field, 2017). A *p*-value of less than .05 was considered statistically significant for all analysis.

4 | RESULTS

PCA extracted three components with eigenvalues greater than one, accounting for 68% of the total variance (Figure 2). The initial component labelled 'working memory capacity', consisting of verbal and complex spatial working memory tasks. The second component labelled 'Planning Ability', consisting of Tower of London, Switching Stroop, and Block Rearrange, as each shared underlying executive function processes consistent with inhibition, attention control, organisation, and planning. The last component labelled 'Reasoning Ability' consisting of 2D manipulations, Feature match and Verbal Reasoning Task, also shared similar underlying processes consistent with tasks that reflect functions of shifting, selective attention, and reasoning. The following descriptions of these higher-order components are as follows: Planning ability involves the formulation and anticipation of potential outcomes before initiating actions (Kaller et al., 2008; Unterrainer & Owen, 2006). On the other hand, Reasoning ability necessitates the capability to establish connections between disparate or dissimilar phenomena. This process entails the manipulation of working memory and the extraction of pertinent information from historical and current data to achieve desired outcomes (Goswami et al., 1998; Krawczyk et al., 2008; Waltz et al., 1999). Latent variables were then produced by regressing task scores onto the rotated component matrix (Table 1).

Correlation analysis revealed total drown detection performance demonstrated statistically significant positive correlations with lifeguard experience ($r = .804$, $p < .001$), WMC ($r = .532$, $p < .001$) and planning ability ($r = .258$, $p < .01$), but not reasoning ability ($r = .133$, $p > .05$). Likewise, correlation revealed lifeguard experience demonstrated statistically significant positive correlations with WMC ($r = .485$, $p < .001$), planning ability ($r = .234$, $p < .05$), and reasoning ability ($r = .133$, $p < .05$). As correlations between lifeguard experience and all cognitive variables were relatively large, further analysis continued to treat experience as a covariate for all regression analysis. To identify whether WMC and high-order executive functions uniquely predict total drown detection performance, a two-step hierarchical regression analysis was conducted. Beta coefficients (β) were used to access the unique variance associated with each variable. Lifeguard experience was added in the first step as a covariate, accounting for 64.7% of the variance, and revealed a significant result ($R^2 = .647$, $F(1,109) = 199.632$, $p < .001$). Cognitive variables were entered into the second step and revealed an additional 3.5% variance in target detection performance over and above that accounted for by lifeguard experience ($\Delta R^2 = .035$, $\Delta F(3106) = 3.942$, $p < .05$). Only

TABLE 1 Rotated component loadings on all cognitive assessment tasks.

Cognitive tasks	WMC	Planning	Reasoning
Backward digit span	**0.922**	0.163	0.024
Digit span	**0.902**	0.152	0.225
Spatial span	**0.887**	0.190	0.175
Blocks	0.178	**0.808**	0.070
Tower of London	0.137	**0.753**	0.073
Switching stroop	0.075	**0.616**	0.144
Verbal reasoning	−0.137	0.111	**0.787**
Feature match	0.351	0.082	**0.726**
2D manipulations	0.332	0.153	**0.646**

Note: Bold = Factor loadings >0.4.

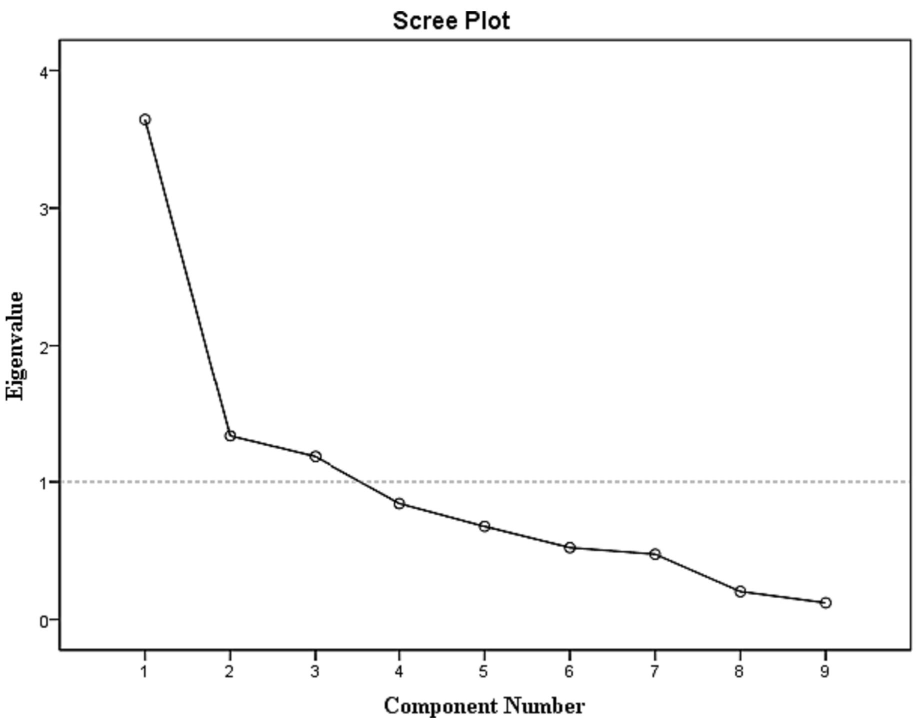

FIGURE 2 Scree plot produced through principal component analysis. Dotted line highlights eigenvalue cut-off (Kaiser, 1960).

TABLE 2 Hierarchical regression analysis predicting drown detection performance from cognitive variables.

		R^2	ΔR^2	ΔF	B	SE_B	β	t	p
Step 1		.647	.647	199.632					.000
	Experience				.022	.002	.804	14.129	.000
Step 2		.683	.035	3.942					.010
	Experience				.019	.002	.688	10.250	.000
	WMC				.373	.120	.198	3.108	.002
	PLAN				.183	.107	.097	1.707	.091
	REAS				−.027	.106	−.014	−.250	.803

WMC provided a significant unique contribution to explaining the variance at this step ($\beta = .198$, $t = 3.108$, $p < .01$), suggesting those with higher scores in WMC perform better at the lifeguard-specific drown detection task. Planning ($\beta = .097$, $t = 1.707$, $p > .05$) and reasoning ability ($\beta = -.014$, $t = -.250$, $p > .05$) failed to provide any unique contribution to explaining the variance at this step. Overall, the final model explained 68.2% of the variance in total drown detection performance (Table 2).

5 | DISCUSSION

As predicted, WMC demonstrated a significant relationship to Bobbing Along task performance with greater WMC scores appearing to outperform those with a lesser cognitive ability. The controlled attention theory of WMC provides some insight by suggesting the cognitive ability reflects an individual's ability to control attention under high cognitive load (Engle & Kane, 2004; Unsworth & Engle, 2007). The control of attention being paramount to ensure attention is not automatically captured by internal or external distraction (Conway & Kane, 2001; Kane & Engle, 2003; Pratt & Hommel, 2003). The present study seemingly implies that WMC constitutes a pivotal determinant in the performance of the Bobbing Along task. This task's demanding nature on cognitive resources has been previously documented (Sharpe et al., 2023). The results tentatively indicate that lifeguards possessing elevated WMC may demonstrate an enhanced ability to sustain task-related concentration (e.g., vigilant monitoring of active bathers) throughout prolonged periods of task engagement.

High-order executive functions of planning and reasoning ability failed to demonstrate a significant relationship with domain specific performance, opposing prior reports (Jacobson & Matthaeus, 2014; Vestberg et al., 2017). As both cognitive abilities have been associated with behaviour regulation and distraction avoidance (Hasher et al., 2007; Unsworth et al., 2010), in addition to the coordination of attention (Krawczyk et al., 2008), our findings were contradictory to our hypothesis. Particularly when such mechanisms appear to be crucial to the role of a lifeguard (e.g., remaining attentive towards multiple bathers). It appears our selected high-order executive functions do not contribute to successful detection performance during the Bobbing Along task. However, such cognitive abilities may still be paramount for the successful performance of lifeguards beyond drown detection, including distress identification, readiness to rescue and provide first-aid, and the application of preventative measures (Hunsucker & Davison, 2008; Petrass & Blitvich, 2014; Petrass & Blitvich, 2017).

Our findings suggest that WMC is related to domain-specific drown detection performance. It appears extended monitoring may be challenging for those with lesser cognitive ability to maintain performance, irrespective of lifeguarding experience. Such decline in performance associated with extended monitoring has been citing as a regular occurrence for individuals to experience (Killingsworth & Gilbert, 2010) and noted as a leading cause for occupational accidents (Edkins & Pollock, 1997). Whilst the following experiment does offer insight into the contribution of WMC during domain specific performance (i.e., a 60-min task), the influence of such cognitive ability was not explored with respect to the maintenance of performance over time or task difficulty. In Experiment 2 we explore the differences associated with high and low levels of WMC on the ability to maintain task performance across varying levels of task difficulty.

6 | EXPERIMENT 2

Commonly discussed in terms of Shallice's (Shallice, 1988; Norman & Shallice, 1986) conception of the supervisory attentional system, attention control is defined as 'a voluntary, effortful cognitive act that serves to maintain information through activation of relevant brain circuitry, inhibit the irrelevant and distracting information that impinges on us at any one time, and suppress prepotent response tendencies that are task irrelevant' (Heitz et al., 2005, p. 64). This system allows an individual to direct attention towards stimuli to ensure the attainment of the current goal and minimise external distraction (Corbetta & Shulman, 2002; Petersen & Posner, 2012; Shallice & Burgess, 1996). The ability to continuously maintain attention to a task, often referred to as sustained attention, is a core aspect of attention control. Sustained attention enables the maintenance and engagement on a task of extended periods (Robertson & Garavan, 2010), whilst a failure of such ability inevitably leads to a vigilance decrement (i.e., the decline in performance during extended monitoring tasks; Warm & Parasuraman, 1987). Insight into the processes that prevent such decrement are unsurprisingly invaluable to the field of lifeguard performance, given a decline in detection performance could result in a bather's death, whilst a delay in detection could result in life changing injuries being sustained through prolonged submersion (Lanagan-Leitzel et al., 2015).

Prior reports have demonstrated the latent variable of WMC as significantly and positively correlating with multiple attention control measures (Robison et al., 2017; Unsworth & McMillan, 2013; Unsworth & Robison, 2017). Whilst sustained attention has seen limited investigation, reports have suggested those with greater WMC are better able to sustain their attention than their lesser cognitively advantaged counterparts (Buehner et al., 2006; Schweizer & Moosebrugger, 2004). Unsworth and Robison (2020) reported that those with high or low cognitive ability initially perform similarly in sustained attention tasks, however as time-on-task duration increased those with low WMC experienced a greater vigilance decrement than high WMC. The cognitive-energetic model of individual differences in WMC and sustained attention (Unsworth & Robison, 2020) suggests intensity of attention may determine task success. Particularly, when intensity of attention is high proper goal selection, activation and maintenance can occur, whilst those with less of an ability to voluntary control the intensity of attention may experience problems with such mechanisms. Authors suggest the relation between individual differences in working memory and sustained attention are due to variation in intrinsic alertness (i.e., control of readiness). That is, a reduced rate of impairments in high working memory individuals may be due to the individual's ability to emphasize the task goal beyond that of their counterparts (Unsworth & Robison, 2020).

From this evidence we hypothesized that a decline in performance over time will be observed, irrespective of cognitive ability, as reported across prior literature (Risko et al., 2012; Thiffault & Bergeron, 2003; Verster & Roth, 2013). However, we predict that low WMC participants will experience a greater decline in performance over time compared to the high WMC participants, as reported previously (Unsworth & Robison, 2017, 2020). We predict that when task difficulty is low no significant differences in performance will be observed between the two groups, whilst WMC will discriminate performance when perceived task difficulty is high (Unsworth & Robison, 2017).

7 | METHODS

7.1 | Participants

In an extreme group design, participants from the upper or lower quartile for WMC from Experiment 1 were invited for Experiment 2. A total of 28 currently certified lifeguards ($M_{\text{age}} = 21.93$, $SD = 2.96$ years), with varying durations of employment in months ($M_{\text{lifeguard employment}} = 31.25$, $SD = 49.38$ months) participated in this study. The high WMC group ($M_{\text{cognitive score}} = 2.17$, $SD = 0.98$) consisted of 3 female and 11 male active lifeguards ($M_{\text{age}} = 23.36$, $SD = 3.29$ years; $M_{\text{lifeguard employment}} = 52.143$, $SD = 63.05$ months), whilst the low WMC group ($M_{\text{cognitive score}} = -0.96$, $SD = 0.15$) consisted of 4 female and 10 male active lifeguards ($M_{\text{age}} = 20.50$, $SD = 1.69$ years; $M_{\text{lifeguard employment}} = 10.36$, $SD = 12.22$ months). The data for this portion of the study was collected across the two-month period that followed Experiment 1. Participants were selected due to their prior performance on the WMC tests during *Experiment 1*, participants were informed of this and were only contacted if they had previously agreed to be contacted for future data collection. Ethical approval for the study protocol was awarded by the lead institution. All participants provided informed consent prior to the onset of the data collection.

7.2 | Drown detection performance tasks

7.2.1 | Bobbing along

The same methodology employed in Experiment 1 was utilized, with the modification that the environment was manipulated by varying the number of actors ('bathers') per mesh (i.e., 1, 2, or 3). Consequently, the 60-min tasks comprised scenarios with 16, 32, or 48 actors respectively (refer to Figure 3), who exhibited randomized movements within the mesh. In the event of a 'drown' occurrence, the pre-designated 'bather' initiated treading-water and subsequently began a drowning process (i.e., gradual submersion) spanning a 30-second interval. Each video showcased uniform swim patterns and consistent timings for drown events across for participants. However, the videos themselves exhibited slight variations concerning drowning locations. Notably, the 32-bather version diverged from the approach employed in Experiment 1. Specifically, the sequencing of drowning events was reversed to mitigate the potential for pattern recognition; however, this may still not mitigate the possibility of participants implicitly learning the general locations/trends of events over the course of testing.

7.3 | Study design & procedure

All testing was carried out within normal working hours (8 am–6 pm) and task conditions were presented in a random order to avoid potential order effects. Participants engaged in a singular 60-min task on each day, spanning three consecutive days. This approach was implemented to prevent potential vigilance decrement linked to multiple testing sessions. Across these three days, participants underwent testing. Specifically, they were invited to the laboratory to participate in the Bobbing Along detection task (see Sharpe et al., 2023, for further information). To ensure participants' comprehension of the target stimuli (i.e., drowning events) and clear visibility of the task, a preliminary practice trial was conducted. Participants were instructed to indicate their observation of an unfolding drowning event (as delineated in Experiment 1). Given that a drowning event occurred at predefined intervals (e.g., every 5, 10, 15 min, etc.), a binary scoring system was employed to represent performance at each of these time points (where 1 indicated a Hit and 0 indicated a Miss). The testing environment remained identical to Experiment 1, including illumination

($M_{\text{Horizonal}}$ = 40.75, SD = 6.937 Lx; M_{Vertical} = 12.86, SD = 3.76 Lx) across all testing (recorded through the LUX LIGHT APP).

7.4 | Data analysis

Data for each observed variable were screened for univariate normality using skewness and kurtosis ratios. Skewness and kurtosis for all measures met criteria for normality. Data were screened for outliers using boxplots. No univariate or multivariate outliers were identified. A mixed design ANCOVA was used to analyse the effect of group (High vs. Low WMC), bather number (16, 32, and 48 bathers) and time (11 drown scenarios) on drown detection performance. Considering the discrepancies in the lifeguarding experience durations observed among the WMC groups, the variable of experience was treated as a covariate for all analyses. A Bonferroni adjustment was employed when multiple comparisons were being made to lower the significance threshold and avoid Type I errors (McLaughlin & Sainani, 2014). Violations of sphericity were corrected for by adjusting the degrees of freedom using the Greenhouse Geisser correction when epsilon was less than 0.75 and the Huynh-Feldt correction when greater than 0.75 (Girden, 1992). The alpha level (p) for statistical significance was set at 0.05.), partial eta squared (ηp^2) was used to measure effect sizes with Cohen's d used for pairwise comparisons (Cohen, 1988).

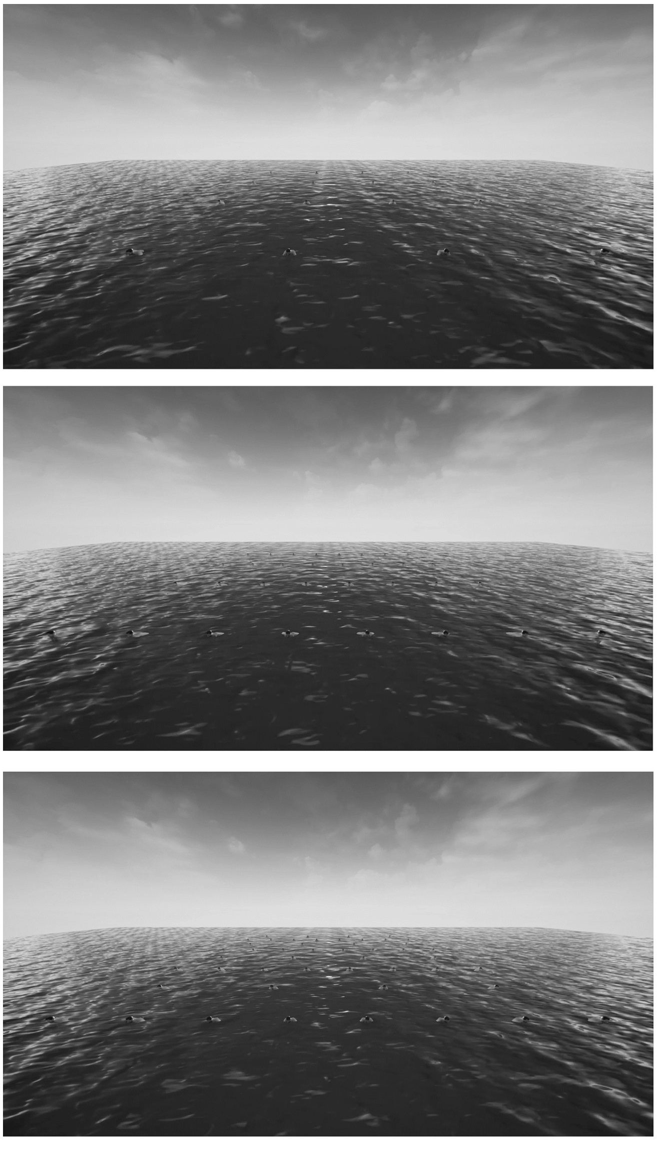

FIGURE 3 Screen captures of the Bobbing Along task manipulations including 16, 32 and 48 bather count, respectively.

8 | RESULTS

8.1 | Main effect

WMC had a significant between-subject main effect on performance ($F(1, 25) = 56.278$, $p < .001$, $\eta p^2 = .692$). The high WMC group ($M_{\text{overall performance}} = 15.21$, SD = 1.76) performed greater than the low WMC group ($M = 10.143$, SD = 1.43; $p < .001$, $d = 1.418$). There was a significant within-subject main effect of time ($F(10, 250) = 12.605$, $p < .001$, $\eta p^2 = .335$) and bather number ($F(2, 50) = 763.231$, $p < .001$, $\eta p^2 = .968$) on drown detection performance. On average performance deteriorated as time progressed.

TABLE 3 Mean (SE) performance scores for bather number across high- and low- WMC groups.

	WMC group	M	SD
16 Bather condition	High	9.29	0.83
	Low	9.00	0.88
32 Bather condition	High	3.86	0.86
	Low	0.79	0.58
48 Bather condition	High	2.07	0.92
	Low	0.36	0.50

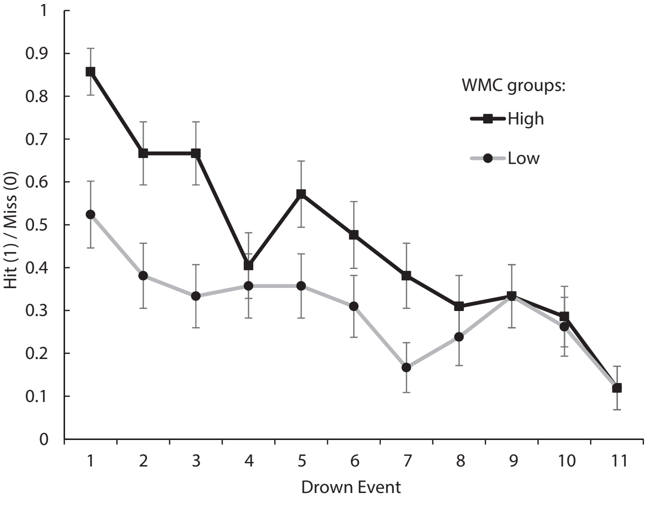

FIGURE 4 The influence of high and low working memory capacity and time on drown detection performance (with SE bars).

Performance was greater when only sixteen bathers crowded the aquatic space ($M = 9.14$, $SD = 0.85$), compared to thirty-two ($M = 2.32$, $SD = 1.72$, $p \leq .001$, $d = 6.772$) and forty-eight bather conditions ($M = 1.21$, $SD = 1.13$, $p \leq .001$, $d = 7.87$; Table 3).

8.2 | Interaction effects

WMC had a significant interaction with time ($F(10, 260) = 3.806$, $p < .001$, $\eta p^2 = .128$). Those with high WMC were better able to maintain a greater level of performance across drown events, whilst those with a low WMC saw a consistently lower level of performance across drown events (Figure 4). After conducting post-hoc t-tests, it was evident that both the high- and low-WMC groups experienced a statistically significant decline in performance from the initial to the concluding occurrence of drown events ($p < .001$). During the intervals between successive drown events, neither group exhibited a statistically significant augmentation or diminishment in performance ($p > .05$), except for the high-WMC group, which demonstrated a noteworthy and substantial reduction in performance between the third and fourth drown events ($M_{\text{difference}} = 26\%$, $SD = 0.67$, $p < .05$). Consequently, the results fail to establish the presence of a consistent vigilance decrement across the specified time points. WMC had a significant interaction with bather number ($F(2, 52) = 26.774$, $p < .001$, $\eta p^2 = .507$). Group differences were not found in the 16-bather condition ($p > .05$, $d = 0.339$), whilst significant differences in group performance were observed across all remaining conditions (all $p \leq .001$, $d = < 2.308$). A significant time × bather number ($F(20, 520) = 5.516$, $p < .001$, $\eta p^2 = .175$) and a significant three-way WMC × time × bather number interaction ($F(20, 520) = 2.390$, $p < .001$, $\eta p^2 = .084$) showed that the number of bathers present, and the duration of the task played a considerable role in the detection of drown events. A consistent vigilance decrement was only present in the thirty-two and forty-eight bather conditions, yet those with high WMC reported higher detection scores overall.

8.3 | Covariate

Statistically significant between-subject main effects of our covariate were present for WMC group ($F(1, 25) = 6.005$, $p < .05$, $\eta p^2 = .194$) with the high- WMC holding a higher duration of lifeguarding experience ($M = 52.14$, $SD = 63.05$) compared to their lesser WMC scoring counterparts ($M = 10.36$, $SD = 12.21$). Irrespective, experience held no significant within-subject interaction effects with bather number ($F(2, 50) = 2.527$, $p > .05$, $\eta p^2 = .092$), time ($F(10, 250) = 1.666$, $p > .05$, $\eta p^2 = .031$), or three-way interactions with bather and time ($F(20, 500) = 1.510$, $p > .05$, $\eta p^2 = .057$).

9 | DISCUSSION

To extend the findings of Experiment 1, we explored the differences associated with high and low levels of WMC on time, as measured by reoccurring drown events, and bather number. Individuals with a high capacity to retain information in an active state during on-going tasks (Baddeley, 2007) significantly outperformed their less advantaged counterparts overall. These findings offer additional empirical support for the conclusions drawn from Experiment 1, shedding further light on the role of WMC as a robust predictor of performance within the chosen task. However, while the low WMC group did hold the lowest performance over time as reported previously (Buehner et al., 2006); they did not experience a decline in vigilance performance compared to the high WMC group as hypothesised. Instead, the observed disparities appear to be rooted in divergent performance proficiencies at various stages of the task. For instance, individuals with high WMC simply detected a greater number of hazards during numerous animated drowning events. While data does not provide a cognitive explanation for the sustainment of attention over time, WMC does appear a valuable tool for determining those best suited for the task at hand. However, given research has demonstrated considerable declines in performance as a function of time (Sharpe et al., 2023), future authors may wish to explore the processes that may mitigate such vigilance decrement.

The presence of an overall vigilance decrement, irrespective of cognitive ability, maintained the theme presented across prior literature (Langan-Fox et al., 2010; Risko et al., 2012; Swanson et al., 2012). With repeated findings suggesting individuals cannot maintain 'optimal' monitoring performance over extended periods, findings may present concern for bathers and lifeguard organisations. Particularly when these periods, in accordance with the Royal Life Saving Society (RLSS) recommendation, may last up to sixty minutes in duration (RLSS, 2017). To combat this decline in performance the RLSS UK National Pool Lifeguard Qualification suggests lifeguards may rotate between positions across fifteen to thirty-minute periods to ensure alertness is maintained. However, the contribution of WMC should be considered and explored further given the observed contribution to the Bobbing Along task performance.

A clear performance advantage was demonstrated across the thirty-two and forty-eight bather conditions. The high WMC group outperformed those with lesser cognitive ability by appearing to maintain goal-directed behaviour towards the tasks for greater periods of time, in line with prior literature (Conway & Kane, 2001; Kane & Engle, 2003; Pratt & Hommel, 2003). The least mentally demanding bather condition (Sharpe et al., 2023), however, failed to demonstrate any group differences in task performance. Our findings are parallel to the work of Sharpe et al. (2023) that found the detection performance of experienced lifeguards were not that dissimilar to that of the novice and naïve groups during the sixteen-bather condition. With reference to the controlled attention theory of WMC, our findings were anticipated given the supposed benefit of the cognitive ability commonly discussed with tasks of high load (Engle & Kane, 2004; Unsworth & Engle, 2007). As such, it appears WMC is a significant discriminator in task performance only when the task is cognitively demanding (e.g., a high bather count). Further, an observable decline in the high-WMC group's performance also became evident at the 20-min mark (drown event 4) before returning descriptively towards a more consistent and predictable pattern. This change could potentially indicate a subtle increase in task difficulty leading a drowning event to be more challenging for lifeguards to identify, thereby underscoring a potential weakness in the task design. Alternatively, it is conceivable that the high-WMC group's attention was momentarily diverted by internal distractions. Nevertheless, it prompts us to question why a similar pattern did not manifest in the low-WMC group. Irrespective of our speculation, findings may simply be a result of random error or other unforeseen variables. Such observed performance variation highlights the value in a future study explicitly testing the tasks external and ecological validity.

10 | GENERAL DISCUSSION

We examined the significance of varying cognitive components to detection performance. Our main finding found that participants with greater WMC could better maintain their drown detection performance under conditions of increased task difficulty, but not consistently over extended periods of time. These findings provide support for the contention that a higher degree of WMC may enable an individual to better maintain cognitive control and avoid periodic failures in goal maintenance (Engle & Kane, 2004). Nevertheless, while the results from experiments 1 and 2 offer insights into the role of WMC in Bobbing Along detection performance, it is imperative to acknowledge that these findings might not universally apply to all lifeguard-specific scenarios. Instead, the present study exclusively underscores performance outcomes within an animated task. Our findings potentially indicate that an individual's level of WMC could potentially impact their ability to detect drownings during tasks characterized by high cognitive load and minimal external diversions. For instance, those possessing elevated WMC might exhibit heightened performance (i.e., greater overall detection accuracy) in demanding environments. Conversely, as a precautionary measure, individuals with lower WMC might benefit from additional support when monitoring under conditions of elevated cognitive demand. Irrespective of our findings, it is advisable for lifeguard training manuals to consider incorporating a segment on the concept of vigilance decrement and its implications for task performance.

10.1 | Generalisability of findings

A diverse range of methodologies has been employed to assess the effectiveness of lifeguards in detecting drowning incidents, from pre-recorded CCTV footage (Lanagan-Leitzel, 2012) to scripted beach recordings (Smith et al., 2020). Each variation of these methodologies introduces variations in terms of task representativeness (i.e., the fidelity with which tasks emulate real-world conditions), complexity, and duration. It is unsurprising that these methodological divergences have emerged as pivotal contributors to the inconsistent findings witnessed within the literature on lifeguard drowning detection (Smith, 2016; Smith et al., 2020), a trend that continues in the present study. The evaluation of lifeguards' direct performance in detecting drownings is inherently constrained when attempting to incorporate uncontrollable scenarios marked by contextual variations. Such limitations encompass dynamic alterations in the visible patrons, fluctuations in bather counts, water-related obstacles, environmental influences like sun-glare and shadows, recordings characterized by limited visual resolution, stimuli lacking domain-specific environmental relevance, and task durations misaligned with lifeguard duties.

The Bobbing Along task, though designed to alleviate some of these challenges by mitigating complexities inherent in a natural environment - such as unpredictable swim behaviours - introduces additional constraints like consistent and potentially predictable drown times, which may present their own challenges. Nonetheless, the allure of such tools is rooted in their capacity to integrate human factors into research designs. Animation offers advantages such as time efficiency (e.g., obviating the need to recruit bathers and orchestrate drowning simulations with trained personnel), cost-effectiveness (e.g., sidestepping expenses linked to renting pool facilities), and ethical considerations (e.g., sparing individuals from simulating drowning scenarios). Within the lifeguard research, animated tasks afford researchers the opportunity to investigate diverse determinants contributing to successful drowning detection performance across an expansive spectrum of scenarios that often prove impractical to replicate in real-world settings. Readers must apply caution when interpreting our, and others, research findings, and future authors must continue to innovate to maximise ecological validity and strive for absolute validity with real-world environments (see Wynne et al., 2019, for a comprehensive review on validity). As such, our findings may merely apply to the chosen task and not necessarily lifeguard detection performance.

10.2 | Limitations and future directions

It is important to recognise that overlapping descriptions of each cognitive process provides difficulty in interpreting data, particularly in determining the functions shared by each task. To tackle this initially the current study used a latent variable approach by taking a set of cognitive tasks and highlighting their shared structure. Such an approach, whilst extending lifeguard research, may not be reflective of all literature exploring these structures. It should be acknowledged that this limitation is present in numerous factor analytic studies of cognition. Most notably, through the differing definitions of cognition adopted throughout literature (Engle, 2002; Unsworth & Engle, 2007), shifts in theoretical approaches (Miyake & Friedman, 2012), and those analysing data using a singular global factor score, separate latent variables, or individual test items (Friedman & Miyake, 2004; Hedden & Yoon, 2006). As such, the adoption of numerous approaches to explore cognition in a lifeguard sample may have resulted in contrasting outcomes. Future research may wish to adapt the methodology reported in the current study to extend the current gap in lifeguard literature. Alternatively, research may wish to explore other commonly employed measures of either construct (e.g., Operation Span, Symmetry Span; Robison et al., 2017; Unsworth & Robison, 2020).

While receiving mixed results, cognitive training may be a direction for future authors to explore. In fact, improvements to daily functions have been reported previously in healthy participants after undertaking cognitive training (Jaeggi et al., 2008; Karbach & Kray, 2009). Given that literature has proposed that attentional control processes may modulate individual differences in WMC (Engle & Kane, 2004; Kane et al., 2007; Kane & Engle, 2002), and that WMC appears to predict performance in the Bobbing Along task, it may be warranted to explore whether WM training would elicit far transfer effects to a real-world drowning detection task. However, we wish to recognise the previously reported challenges associated with eliciting far transfer effects beyond the trained function (Brehmer et al., 2012; Redick et al., 2020).

11 | CONCLUSION

Across a series of two experiments, we attempted to identify whether WMC and high-order executive functions uniquely predict total drown detection performance, and whether the highlighted cognitive component of working memory capacity held any predictive utility in terms of the maintenance of performance under conditions of increased task difficulty and over extended periods of time. Our key finding demonstrated that that individuals with elevated WMC demonstrated an ability to detect a greater number of drowning events over an extended period overall, relative to their counterparts scoring in the lower cognitive assessment. However, this heightened capacity did not necessarily prevent the presence of vigilance decrement, but enabled lifeguards to perform more effectively under conditions of increased bather numbers. Our findings highlight that lifeguards have a measurable underlying process that may systematically discriminate lifeguards of varying degrees of experience and detection performance. This has highlighted processes that may have applied application in the recruitment and training of lifeguards, if explored further. Independent of cognition, this work presents a clear limitation in a lifeguard's ability to sustain attention over extended periods and must be explored further. The current findings present another avenue for future research that has yet to be explored within lifeguarding.

CONFLICT OF INTEREST STATEMENT

The authors hold no conflicts of interest associated with the publication of the following manuscript. Ethical approval for the study protocol was awarded by the lead institution.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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