International Journal of Aquatic Research and Education

Volume 13 | Number 4 Article 10

3-10-2022

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Recommended Citation
Vignac, Élie; Lebihain, Pascal; Guignard, Brice; Heutte, Natacha; Le Minor, Loic; and Soulé, Bastien (2022) "Ability of Lifeguards to Detect Submerged Manikins in Public Swimming Pool Environments," *International Journal of Aquatic Research and Education*: Vol. 13: No. 4, Article 10.
DOI: https://doi.org/10.25035/ijare.13.04.10
Available at: https://scholarworks.bgsu.edu/ijare/vol13/iss4/10

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Cover Page Footnote

We would like to thank the urban community of Grand Poitiers (France) and the sports department for making the pools available graciously. We also thank the professional lifeguards who volunteered and the students from the Faculty of Sport Sciences of Poitiers who agreed to simulate the presence of the crowd.

Authors

Élie Vignac, Pascal Lebihain, Brice Guignard, Natacha Heutte, Loic Le Minor, and Bastien Soulé

Abstract

To prevent drownings in public swimming pools (PSP), French legislation requires constant surveillance by state-certified lifeguards. While previous research showed that surveillance was not always effective, this article focuses on efficiency of surveillance when it is effective. We evaluated the ability of 4 volunteer professional lifeguards to detect a submerged manikin under controlled conditions. One hundred and eight (108) tests were carried out in 2 PSP. Four variables were controlled (i.e., distance, depth, surveillance station, attendance). Our results showed that rapid drowning detection was not exclusively linked to the individual detection capabilities of a lifeguard, but rather it emerged from a tight coupling between the lifeguard's perception and his/her working environment. The tests performed in this study are useful to prevent drownings and therefore should be reproduced in other public swimming pools (i) to identify problematic situations and (ii) to train lifeguards' surveillance capabilities.

Keywords: drowning prevention, surveillance, lifeguarding, water safety

Introduction

Since 2001, France has recorded drowning incidents that occurred in public swimming pools (PSP). Although these surveys have limitations (e.g., performed only between the 1st of July and the 30th of September, every two years), the data revealed for each edition about forty drowning incidents. Among them, about ten are fatal (Ung et al., 2019). An extrapolation is required to better approximate drowning prevalence: these numbers rise to about 150 drowning incidents each year with about 20 leading to death (Vignac et al., 2015). Drowning incidents unfortunately happen despite the presence of qualified lifeguards while bathing area is supposed to be constantly supervised according to French legislation requirements. Deficient surveillance frequently has been designated as a cause of drowning (Belhache, 2010; Vial, 2012).

The role of professional pool lifeguards (PPLs) remains crucial because they are the primary line to prevent a drowning incident to occur. Indeed, the survival (ideally without sequelae) of a person in distress is greatly dependent on rapid detection and intervention (Bierens et al., 2016; Claesson et al., 2008; Hunsucker & Davison, 2010; Quan, 2016; Szpilman, 2014). A bibliographic study (Coblentz et al., 2001) showed that human surveillance is never 100% reliable. Missed detections may be relatively frequent (Mollard, 2014). PPLs, who work in a sensory-harsh environment (Schwebel et al., 2007) must bear this in mind as surveillance is one of their core responsibilities. The amount of time spent monitoring has a significant influence with the percentage of missed detections rising significantly after 30 minutes (Mollard, 2014). In addition, Mollard (2014) pointed out that noise (Hockey, 1978) and high temperatures (Mackworth, 1950;

Pepler, 1953) significantly reduce surveillance performance. The monotony of the surveillance task and the relative infrequency of critical events can also lead to inattention with a negative impact on performance (Perkins, 1985). Unfortunately, PPLs are sometimes placed in a work and organizational context that is incompatible with optimal surveillance (Vignac et al., 2017). All these parameters are considered as *constraints* that continuously bound the emergence of saving behaviours of the PPLs (please refer to Newell (1986) regarding the concept of constraints). It implies that the PPLs behaviours cannot be dissociated from their surveillance environments, considered as the smallest relevant unit of analysis for understanding the detection (i.e., visual perception) and intervention (i.e., action) mechanisms of a drowning incident. Theoretically, ecological dynamics is a framework which integrates those concepts (Araújo et al., 2006; Araújo et al., 2012; Davids et al., 2015) in the sense that perception directly guides an individual's action, and, in turn, his/her actions shape on-going perceptions (i.e., these couplings support performance behaviours) (Davids et al., 2015).

Applied to surveillance in PSP, recent studies focused on the visual scanning techniques of PPLs (Harrell & Boisvert, 2003; Hunsucker & Davison, 2008; Schwebel et al., 2007). For example, the detection capabilities and strategies of lifeguards as they view video-projected swimming scenes of bathing was tested using eye tracking devices (Lanagan-Leitzel et al., 2015; Page et al., 2011; Page & Griffiths, 2016). To our knowledge, little research focused on the detection capabilities of PPLs in *real* surveillance conditions with the notable exception of the investigations of Ellis and colleagues (Brener & Oostman, 2002; Griffiths, 2016; Patterson, 2007). This is, however, a significant point to consider in ecological dynamics since sport scientists must design *representative* practice tasks that simulate the reference environments (e.g., surveillance of a PSP) to ensure adaptability and skill transfer (e.g., detection of a drowning incident in a minimum of time) (Brunswik, 1956). Therefore, there is a strong need to investigate the PPLs surveillance in ecological conditions and not only mediated by the use of a video screen.

Since previous research highlighted that constant surveillance occurred only about half the time (Vignac et al., 2016), one can wonder whether what is typically considered effective surveillance is actually efficient? In order to answer this question, the detection time of a submerged victim in PSP was used as an indicator of performance. The safety requirements of the ISO 20380(E):2017 standard for the drowning detection by computer vision system recommends an alarm set off time ≤15 s (part 4.3.1, p.3)[iii]. By manipulating constraints that are representative of the context of performance (e.g., submersion of a manikin that simulates a human body during a drowning incident in a PSP), we sought to characterise the detection ability of PPLs. Precisely, we hypothesised that the visual perception and detection of the manikin by the PPLs (i.e., their detection ability) may be negatively affected by a large pool attendance, a deep pool, but also by a static and low position of the PPLs with regards to the pool (i.e., restricted perception of the pool and its users). Additionally, we hypothesised that the closer the PPL were from the manikin, the shorter the detection time ought to be due to facilitated perception of it. Many authors have encouraged this type of approach to expand knowledge in the field of aquatic safety (Griffiths, 2008; Hunsucker & Davison, 2008; Lanagan-Leitzel et al., 2015).

Method

Participants

Four professional volunteer lifeguards in a work situation at two facilities participated in the collaborative tests by trying to detect as quickly as possible a manikin submerged in the monitored pool. In order to avoid finding them at fault with potential stigmatization, individual PPLs were not considered as a variable to be tested or controlled (Arendas, 2016).

Protocol

The tests were carried out in three pools at two public swimming pool facilities in Greater Urban Area of Poitiers, France. Both facilities were closed for the study duration. The protocol was designed to reproduce the conditions of public pool use as a function of a percentage of the maximal number of people allowed (MNA) in each facility (see Table 1).

Table 1

Determination of the number of pool users as % of maximal number allowed (MNA)

Facility / pool		**PPL**	**MNA**	**Pool surface**	**Number of swimmers based on MNA**		
					Low (10%)	Intermediate (25%)	High (40%)
Bellejouanne	**Learning**	2	160	300 m^2	16	40	64
Pépinière	**Fitness**	1	150	200 m^2	15	37	60
	Recreational	1	300	300 m^2	30	75	120

[i] Refer to Endnotes

The protocol was conducted in accordance with the ethical standards of the declaration of Helsinki. The project and the method implemented have been approved by the elected community of Grand Poitiers. All participants (professional lifeguards and the public who used the pools) received an informational letter about the protocol and its aims. Their participation was voluntary and unpaid. No information was collected/transmitted about the identity of the participants (lifeguards and members of the public). It was therefore not possible to re-identify them. Individual detection performances were not communicated to the lifeguards' employers.

Prior to the current investigation, we asked PPLs to distinguish between an apneist (human trained to hold their breath for an extended time period) and a submerged manikin which had the size of an adult man, both wearing bathing suits and dark swim caps. At the end of this preliminary phase of the test, we found that the PPLs were unable to distinguish between the two. Therefore, our weighted humanoid manikin (see Fig. 1A) was realistic enough to enable us to avoid the risk of soliciting an apneist because long and repeated apneas especially combined with hyperventilation are potentially extremely dangerous.

Nearly 200 students from the University of Poitiers simulated the presence of public pool users. They were instructed to disperse themselves evenly throughout the pool and not to look at the submerged manikin. This made it possible to control the number of pool users as a variable, since the presence of real pool users would have interfered in the detection of the submerged manikin (Patterson, 2007). Such simulated situations among uninformed individuals can be potentially shocking for bathers and are unethical (Arendas, 2016). Finally, we used a prototype watchtower (i.e., a mobile construction scaffold), which is higher than the usual surveillance chair in order to test the relevance of an elevated view (the PPLs foot level was set at 2.3 m; see Fig. 1B).

Photograph 1

Photographs of technical supports selected and used in the present study. A: Adult-size submerged manikin in dorsal position; B: Prototype watch-tower used for the tests; and C: Professional pool-lifeguard about to remove the eye mask

Tests

The tests were conducted as follows: (1) the eyes of the on-duty lifeguard were covered, (2) the manikin was submerged (according to the 4 variables in Table 2), (3) the lifeguard's eyes were uncovered (Photograph 1C), and (4) the time to manikin detection was recorded (in cases of non-detection, we ended the test after 2 minutes). For each detection, the lifeguard had to lead the researcher to the detected manikin (by explicitly pointing at it). We did not perform a control test (without submerged manikin) because the primary purpose of the study was to measure the detection time of an immersed look-like body. However, we acknowledge that these situations (underwater immobile body) correspond broadly – and fortunately – to a small minority of instances under real PPLs surveillance.

Variables and Precautions

Independent variables were submersion depth, number of pool users (% MNA), submersion zone (i.e., distance of the manikin from the lifeguard), and surveillance station (Table 2).

Table 2

Variables and subvariables

Variables	**Subvariables**
Submersion depth	Shallow (0–1.10 m)
	Average (1.11–1.80 m)
	Deep (>1.80 m)
No. of pool users (expressed as % of maximal number allowed: MNA)	Low (10% of MNA)
	Intermediate (25% of MNA)
	High (40% of MNA)
Submersion zone (distance of manikin from PPL)	Near (1st third of pool)
	Mid-distance (2nd third of pool)
	Far (3rd third of pool)
Surveillance station	Low-to-ground (seated or standing)
	High lifeguard chair
	Moving position (walking around the pool)
	Watchtower (feet at 2.3m high)

[ii] Refer to Endnotes

To test all the variables in combination, we conducted 108 submersions. None of the submersions occurred in areas where we knew the manikin would not be visible from the surveillance stations. It should be noted that is it not uncommon to have pool zones that are not visible from the surveillance stations due to blind spots or obstacles (e.g., plants, decorations, features like slides and flumes) that limit the scanning and surveillance capabilities of the PPLs (Patterson, 2007;

Loussot & Lebihain, 2014). The zones that were not visible from the surveillance stations were determined in consultation among the researchers and facility staff during the pilot test phase.

Data Collection and Statistical Analysis

The results were processed using Excel (Microsoft Office). The ISO 20380 (E):2017 standard was used as a threshold to frame the presentation of the results and box plots summarised statistics on time detection (Figure 1). At the end of the submersion tests, the influence of the variable modality on submersion time was assessed using the chi-square of independence test (Table 3), the Wilcoxon test or the Kruskal-Wallis test, as appropriate (Figure 1 and Table 4).

Table 3

Description of detection times as a function of explanatory variables

Time to detection Direct vision decimal (in sec)	n*	DM**	Mean	SD***	Min	Max	Median	q1****	q3*****	Wilcoxon or Kruskal-Wallis test, p-value******
	96	12	18.10	22.88	1.00	113.00	8.00	3.00	20.50	
Pool Facility										0.9267
Bellejouanne	29	7	19.31	23.94	1.00	89.00	11.00	3.00	20.00	
Pépinière	67	5	17.58	22.57	2.00	113.00	8.00	3.00	21.00	
Pool										0.6546
Fitness	34	2	17.91	23.44	2.00	113.00	8.50	4.00	18.00	
Recreational	33	3	17.24	22.01	2.00	80.00	7.00	3.00	21.00	
Learning	29	7	19.31	23.94	1.00	89.00	11.00	3.00	20.00	
No. of swimmers										0.2494
Low	34	2	19.79	22.85	2.00	89.00	12.00	5.00	21.00	
High	30	6	20.90	28.61	1.00	113.00	7.00	2.00	45.00	
Intermediate	32	4	13.69	15.89	1.00	80.00	8.00	3.00	17.00	
Distance										<.0001
Far	28	8	30.21	27.06	1.00	113.00	20.50	12.00	45.50	
Mid	33	3	16.03	20.08	1.00	80.00	8.00	4.00	15.00	

Time to detection Direct vision decimal (in sec)	n*	DM **	Mean	SD***	Min	Max	Median	q1****	q3*****	Wilcoxon or Kruskal-Wallis test, p-value******
Near	35	1	10.37	17.76	1.00	81.00	3.00	2.00	9.00	
Depth										0.0007
Shallow	23	1	9.70	17.52	1.00	81.00	3.00	2.00	9.00	
Average	64	8	18.77	22.66	1.00	113.00	9.50	4.50	21.50	
Deep	9	3	34.89	28.41	1.00	89.00	23.00	19.00	45.00	
Surveillance station										0.1260
Low-to-ground	22	5	25.09	32.28	1.00	113.00	11.50	3.00	22.00	
High chair	21	6	22.24	25.28	2.00	80.00	13.00	5.00	28.00	
Moving	27	0	16.48	17.63	2.00	71.00	8.00	5.00	24.00	
Watchtower	26	1	10.54	12.66	1.00	51.00	4.00	2.00	18.00	

* n: sample size
** DM : Data missing
*** SD : standard deviation
****q1 : first quartile
***** q3 : third quartile
****** red values denote significant differences at p<.05

The Kaplan-Meier method was used to estimate the probability of non-detection. This is a nonparametric reference method to estimate the probability that an event will occur in the presence of censored data (detection failure after 2 minutes). The estimates in each group were compared using the log-rank test (Machin, Cheung, & Parmar, 2006). Logistic regression on the time detection status (≤15 s versus >15 s) as the dependent variable was performed to identify the independent predictors of detection with a backward selection (Table 5). Statistical significance was defined as p<0.05. All tests were two-sided and performed on SAS software (release 9.4).

Results

Of the 108 submersions, 96 manikins (88.8%) were detected in ≤120 s (Table 3 and 4). Of these 96 detections, 62 (64.58%) were made in ≤15 s. The overall mean detection time was 18.1 s (SD=22.9) (Table 4).

Overall, submersion zones (facility: $p=0.9267$, pool: $p=0.6546$) did not affect the detection times, nor did the number of pool users ($p=0.2494$) or the type of surveillance station ($p=0.1260$) (Table 3 and Figure 1). Moreover, no significant differences in the distribution of detections ≤15 s versus >15 s were noted in relation to location (facility: $p=0.4216$, pool: $p=0.6609$), number of users ($p=0.3817$) or surveillance station ($p=0.6423$).

In contrast, the results showed that the manikin distance from the lifeguard had a significant influence on the detection times ($p<0.0001$). The mean detection time when the manikin was far was 30.21 s; it was 16.03 s for mid-distance, and 10.37 s for near. The maximum detection time was respectively 113 s for far, 80 s for mid-distance and 81 s for near. Similarly, we observed that most of the detections made in ≤15 s were near (n=28, 80%) or at mid-distance (n=25, 75.76%), whereas most of the detections made in >15 s were far (n=19, 67.86%), revealing a significant effect of immersion distance ($p=0.0001$).

The water depth in which the manikin was submerged also had a significant influence on the detection time ($p=0.0007$). The mean detection time was respectively 34.89 s for deep, 18.77s for average, and 9.70 s for shallow. The maximum detection time was respectively 113 s for average, 89 s for deep and 81 s for shallow. Depth ($p=0.0113$) significantly impacted the detection time (≤15 s versus >15 s) of the submerged manikin.

The proposed variables for the multivariate model were distance, number of pool users, depth, and surveillance station. In the initial model, distance ($p=0.0015$) and surveillance station ($p=0.0002$) were the only significant variables when all were competing. All variables being equal, the final model showed that near distance increased the likelihood of detecting a submerged manikin in ≤15 s by 4.3-fold (95% CI = [2.507-7.399]) compared with a far distance. Mid-distance increased the likelihood of detection in ≤15 s by 2-fold (95% CI = [1.201-3.334]) compared with far distance. Compared with the high lifeguard chair, the watchtower prototype increased the detection likelihood by 3.4-fold (95% CI = [1.836-6.292]), and walking increased it by 2.8-fold (95% CI = [1.526-5.168]). In contrast, the low-to-ground position did not significantly differ from the high chair (relative risk=1.3, 95% CI = [0.710-2.377]).

Possible detections

On the one hand, analysis of detection times in the presence of censored data (i.e., by taking into account the lack of detections after 120 s) (Fig. 3) showed that the facility ($p=0.0891$), pool type ($p=0.2357$) and number of pool users ($p=0.6393$) had no significant impact.

Table 4
Description of time to detection in ≤15 s versus >15 s as a function of the explanatory variables

	Total number		Time to detection ≤15 s		Time to detection >15 s		Chi^2 test
	n	%	n	%	n	%	p-value
All facilities	96	100.00	62	64.58	34	35.42	
Pool facility							
Bellejouanne	29	30.21	17	58.62	12	41.38	0.4216
Pépinière	67	69.79	45	67.16	22	32.84	
Pool							
Fitness	34	35.42	22	64.71	12	35.29	0.6609
Recreational	33	34.38	23	69.70	10	30.30	
Learning	29	30.21	17	58.62	12	41.38	
No. of swimmers							
Low	34	35.42	19	55.88	15	44.12	0.3817
High	30	31.25	20	66.67	10	33.33	
Intermediate	32	33.33	23	71.88	9	28.13	
Distance							
Far	28	29.17	9	32.14	19	67.86	0.0001
Mid	33	34.38	25	75.76	8	24.24	
Near	35	36.46	28	80.00	7	20.00	
Depth							
Shallow	23	23.96	18	78.26	5	21.74	0.0113
Deep	9	9.38	2	22.22	7	77.78	
Average	64	66.67	42	65.63	22	34.38	
Surveillance station							
Low-to-ground	22	22.92	12	54.55	10	45.45	0.6423
High chair	21	21.88	13	61.90	8	38.10	
Moving	27	28.13	19	70.37	8	29.63	
Watchtower	26	27.08	18	69.23	8	30.77	

Table 5

Results of multivariate analysis on detection in ≤15 s or >15 s: initial and final models

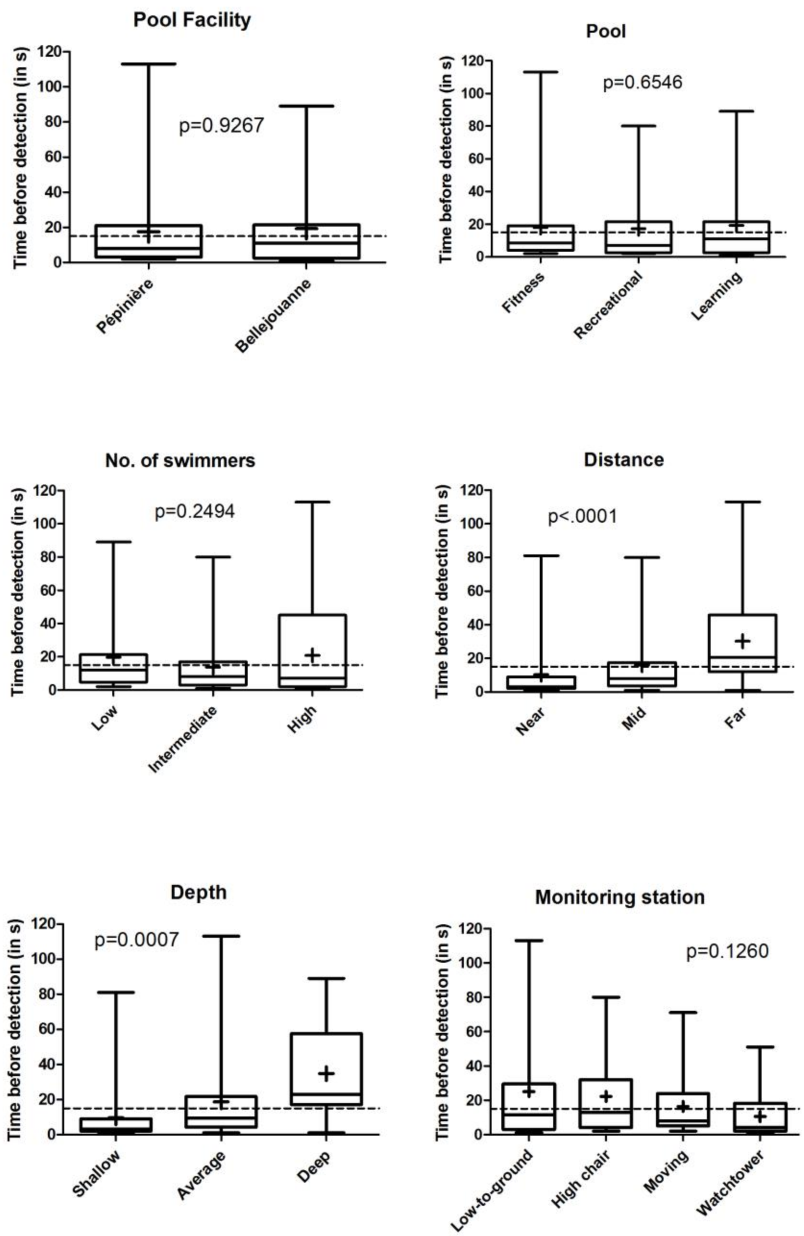
		Initial model*			Final model*		
Variable	**Submersion**	**Relative risk**	**95% CI****	**P value**	**Relative risk**	**95% CI****	**p value**
Distance							
Far	28	1.0		0.0015	1.0		<.0001
Mid	33	1.899	1.071-3.370		2.001	1.201-3.334	
Near	35	4.050	1.880-8.727		4.307	2.507-7.399	
No. of swimmers							
High	30	1.0		0.8295			
Low	34	1.143	0.684-1.910				
Intermediate	32	1.162	0.688-1.961				
Depth							
Deep	9	1.0		0.9367			
Shallow	23	1.177	0.403-3.433				
Average	64	1.158	0.521-2.572				
Surveillance station							
High chair	21	1.0		0.0002	1.0		0.0002
Low-to-ground	22	1.333	0.724-2.453		1.299	0.710-2.377	
Moving	27	2.832	1.538-5.214		2.808	1.526-5.168	
Watchtower	26	3.327	1.787-6.194		3.399	1.836-6.292	

*Results of multivariate analysis on detection in ≤15 s or >15 s

** Confidence interval

Figure 1

Box plots of times to detection as a function of the variables.



Note: The straight-line segment stretching from the smallest to the largest data value was drawn on the vertical axis; a box was then superposed on the line, starting at the first quartile and ending to the third, with the value of the second quartile indicated by a horizontal line inside the box. A "+" was added to represent the mean. The horizontal dotted line symbolized the maximum of 15 seconds to detect a submerged victim, as recommended by ISO 20380 (E):2017.

In contrast, the results showed that the manikin distance from the lifeguard had a significant influence on the detection times ($p<0.0001$). The mean detection time when the manikin was far was 30.21 s; it was 16.03 s for mid-distance, and 10.37 s for near. The maximum detection time was respectively 113 s for far, 80 s for mid-distance and 81 s for near. Similarly, we observed that most of the detections made in ≤15 s were near (n=28, 80%) or at mid-distance (n=25, 75.76%), whereas most of the detections made in >15 s were far (n=19, 67.86%), revealing a significant effect of immersion distance ($p=0.0001$).

The water depth in which the manikin was submerged also had a significant influence on the detection time ($p=0.0007$). The mean detection time was respectively 34.89 s for deep, 18.77s for average, and 9.70 s for shallow. The maximum detection time was respectively 113 s for average, 89 s for deep and 81 s for shallow. Depth ($p=0.0113$) significantly impacted the detection time (≤15 s versus >15 s) of the submerged manikin.

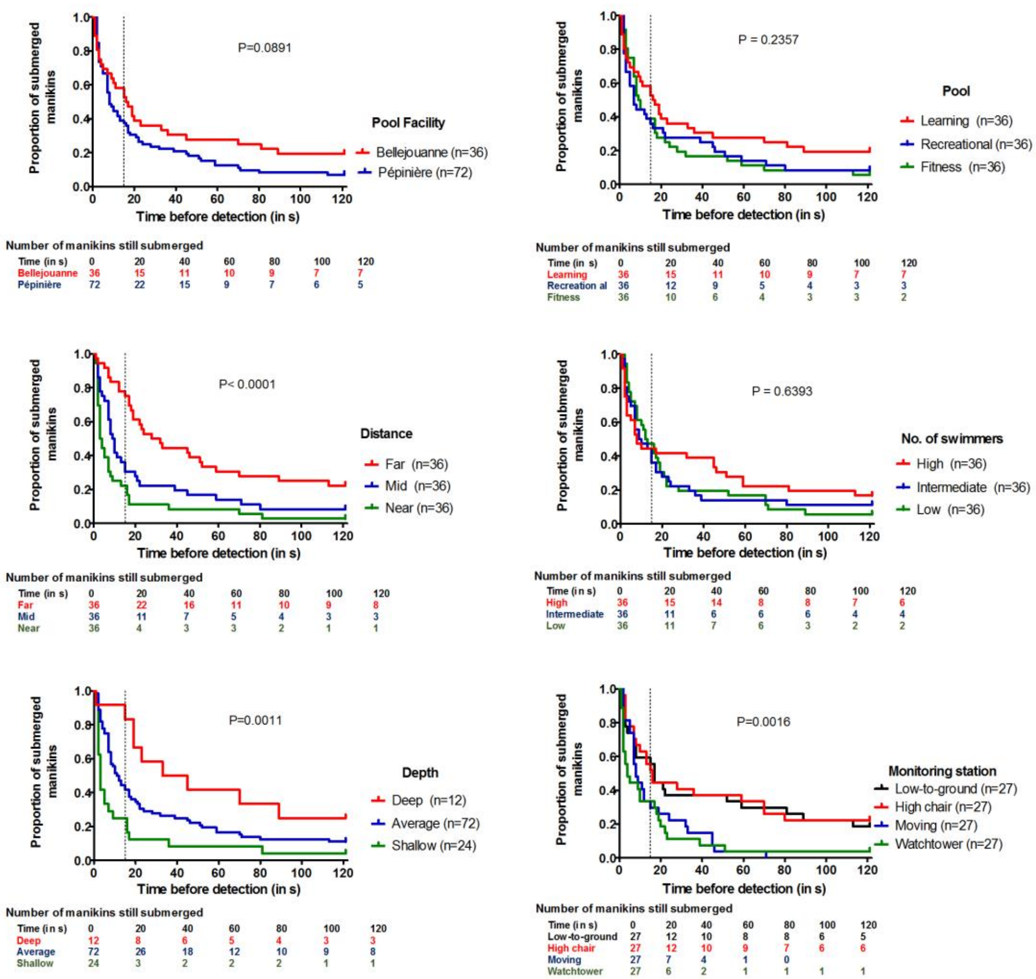
The proposed variables for the multivariate model were distance, number of pool users, depth, and surveillance station. In the initial model, distance ($p=0.0015$) and surveillance station ($p=0.0002$) were the only significant variables when all were competing. All variables being equal, the final model showed that near distance increased the likelihood of detecting a submerged manikin in ≤15 s by 4.3-fold (95% CI = [2.507-7.399]) compared with a far distance. Mid-distance increased the likelihood of detection in ≤15 s by 2-fold (95% CI = [1.201-3.334]) compared with far distance. Compared with the high lifeguard chair, the watchtower prototype increased the detection likelihood by 3.4-fold (95% CI = [1.836-6.292]), and walking increased it by 2.8-fold (95% CI = [1.526-5.168]). In contrast, the low-to-ground position did not significantly differ from the high chair (relative risk=1.3, 95% CI = [0.710-2.377]).

Possible detections

On the one hand, analysis of detection times in the presence of censored data (i.e., by taking into account the lack of detections after 120 s) (Figure 2) showed that the facility ($p=0.0891$), pool type ($p=0.2357$) and number of pool users ($p=0.6393$) had no significant impact.

Figure 2

Proportion of non-detections across time according to the variables. The vertical dotted line symbolized the maximum of 15 seconds to detect a submerged victim, as recommended by ISO 20380 (E):2017.



The type of surveillance station had a significant impact (p=0.0016) on the time to detection. The largest proportion of long detection times concerned the fixed surveillance stations (similar for low-to-ground and high chair positions [p=0.8487]). The moving station and watchtower prototype contributed to reducing the submersion time in similar fashion (p=0.4530). The intermediate detection time was respectively 17 s, 16 s, 8 s, 4 s for the fixed low-to-ground position, the fixed high chair position, moving, and the watchtower prototype. At the end of 2 minutes, 5 manikins remained undetected for the low seat, 6 for the high chair, 0 for moving, and 1 for the watchtower.

Depth also had a significant influence (p=0.0011) on the time to detection with the biggest proportion of missed victims located in the deepest zones. Shallow depth contributed most to reducing the detection time. The median detection time was 39 s, 11.5 s and 3 s respectively for the deep, average and shallow submersions. At the end of 120 s, 3 manikins were still submerged in deep zones, 8 in average depth zones and 1 in shallow depth.

Finally, manikin distance from the lifeguard had a significant influence (p<0.0001) on the time to detection. The largest and the smallest proportions of manikins that remained submerged were at the farthest and at the nearest distances, respectively. The lifeguard’s proximity to the submerged manikin thus helped to reduce the detection time. The median detection time was respectively 30 s, 9.5 s and 3.5 s for far, mid- and near distances. At the end of the 120 s, 8 manikins remained undetected at the far distance, 3 at the mid-distance, and 1 at the near distance.

Discussion

Our study highlighted that half of the detections (50%, n=54/108) took between 0 and 10 seconds. In the meantime, the manikins were considered undetected (because the detection time was longer than 2 minutes) in 11.1% of the cases (n=12/108). As expected, these general results seem better than those of Brener and Oostman (2002) who showed in a study part of a secret audit process that 59% of their submerged manikins were detected by lifeguards in one minute or less and 24% in 2 minutes or more (i.e., 163 cases out of 682 tests). Rapid detections are of primary importance to support life in such accidental situations, since it will contribute to limit the effects of hypoxia (caused by prolonged submersion) on the central nervous system (Mathon, Aymard, Kretyl, & Levraut, 2011). This was conceptualised as the international ISO 20380(E):2017 standard, which advocates detection of a submerged victim in a public swimming pool in less than 15 seconds. Despite a favourable context for rapid detection, only half the cases (45.37%, n=49) met this criterion in the present study. Although our tests were conducted openly (i.e., lifeguards knew there was a submerged manikin) and our sample was not comparable in size than the one of Brener and Oostman (2002), it highlighted the common difficulty for PPLs to detect a submerged manikin, particularly because of the refraction of light on the water surface (see Griffiths (2016) for educational purposes).

Light refraction is therefore one of the constraints that challenges the perception of a submerged body by PPLs in a public swimming pool. The modulation of the line of sight in the present study (i.e., modifying the perception by testing different surveillance stations) was performed to investigate their possible impacts on the performance. Our model highlighted that using the watchtower prototype (or moving alongside the pool) significantly increased the number of detections performed in less than 15 s in comparison to a traditional high lifeguard chair. From an ecological dynamics theoretical rationale, it highlighted how perception is considered an active process (Gibson, 1979) in which individuals seek information (e.g., dynamic visual information to detect a drowning person) and optimize it to act (e.g., in a second time by diving in the pool to save the person).

The perception of a submerged body was likewise linked to the absolute distance (i.e., distance and depth) that separates it from the surveillance position of the PPL. We initially hypothesised that the closer the PPL was from the manikin, the shorter the detection time and our results were heading in this direction. This absolute distance significantly influenced the detection time by increasing it when the submerged body was far away from the lifeguard and deeper under the surface, but there is also a significant effect of the distance and the depth for the repartition of detections below and above the 15 s threshold, leaving the longer detection times for far distances and deepest submersions. To go further, we modelled that PPLs were 4.3 more likely to detect a submerged body in less than 15 s when the distance was near in comparison to a far distance.

Such results reinforced the importance for PPLs to perform a moving surveillance following a random path alongside the pool to improve their perception capabilities. This is crucial since our study highlighted that 22.2 and 25% of the submerged manikins remained undetected when the distance was far from the lifeguard and manikin was in deep water, respectively. To summarise, our results obtained in France were similar to those of Patterson (2007) who used a multifactor approach to characterise the PPLs abilities to identify a submerged body in a PSP. Patterson particularly noted that light refraction, blind spots, the turbidity of the water (e.g., generated by jets, swimmers' movements, bubbles, and wave systems), and the depth and colour of the walls served as negative constraints that may reduce the PPLs ability to perceive a submerged manikin. Just as we found, his research concluded that: (1) the lifeguard must be very close in order to detect a victim (within 10 m when the water is clear and 2 m when the water is cloudy), and (2) surveillance while walking around the pool (with short and regular circuits) optimizes the chances of detecting a submerged body.

By manipulating and evaluating the effects of several variables on the detection time, we identified that distance, depth, and surveillance station were the most salient constraints that impacted the emergence of the PPLs saving behaviour (i.e., detection of the submerged manikin). These results were obtained in a context that was designed to be somewhat *representative* of the PPLs daily practice, notably due to the presence of pool users. Since the PPLs had to perform a real detection (i.e., they did not face a screen on which a life-threatening situation was video-projected) it was more realistic. To our knowledge, such representative design is crucial in the ecological dynamics framework to 'adequately sample informational variables from the specific performance environments', and ensure the functional coupling between perception and action processes' (Pinder, Davids, Renshaw, & Araújo, 2011). Therefore, in the field of PSP surveillance, there is a strong interest in selecting relevant and representative variables that may facilitate the transfer of skills in order for the PPLs to rapidly detect a drowning incident and act correspondingly to save a life. For this reason, the inclusion of pool users was determinant, although that the volunteers of the present study were instructed to ignore the submerged manikin, depriving the PPLs of alert signals that often are considered as a crucial resource for detection and intervention (Arendas, 2016; Patterson, 2007; Vignac et al., 2017).

The results showed that the detection of a manikin by professional lifeguards was mainly affected by the manikin's submersion depth and the distance between the manikin and the lifeguard. They also showed that the time the manikin remained submerged was mainly affected by the depth of submersion, the distance between the manikin and the lifeguard, and the type of surveillance station where the lifeguard was positioned. Based on our findings, the surveillance of public swimming pools may be improved due to the use of a surveillance platform that overlooks the pool from a height of more than 2.3 meters, positioned as close as possible to "risky" areas, especially for deep pools. In the meantime, we recommend giving preference to moving surveillance with, for example, regular rotations at least every 20 minutes. Indeed, placing fixed high lifeguard chair surveillance stations side-by-side should be avoided because they give the PPLs the same view and the same eye-level impact. The tests performed in this study were useful to prevent drownings and should therefore be reproduced in all public swimming pools to clearly (i) identify problematic situations and configurations and then (ii) remedy them.

Limitations

Finally, we identified a couple of potential limitations that must be considered for the design of future research studies. Despite our approach that sought to manipulate constraints that were representative of a real life-threatening situation, we acknowledge that all PPLs in the study initially knew that a manikin had been submerged, implying that their attention was actively and exclusively dedicated to locating it as quickly as possible (Hunsucker & Davison, 2013). Therefore, surveillance was here restricted to the ability to detect a completely submerged and immobile manikin at the bottom of the pool, depriving the PPLs of the stimuli in the aerial phase of aquatic distress (Pascual-Gómez, 2016; Pia, 1974).

Other disruptive constraints such as physiological and cognitive PPL loads (Mollard, 2014) or organizational, sociological factors may hinder the detection of a person in distress (Lanagan-Leitzel, 2012; Vignac et al., 2017). For instance, the high number of submersions performed in the tests may generate learning and expertise effects favourable to more rapid detection (Hunsucker & Davison, 2008; Lanagan-Leitzel et al. 2015; Laxton & Crundall, 2017; Page, 2016; Patterson, 2007). Finally, because the protocol was particularly time-consuming and the situation was complex to simulate (120 participants, each pool closed to the public for one day), for reasons of feasibility, these cumulative constraints forced us to limit the number of trials and participants. These limitations all should be taken into account before transferring the present results to other pool surveillance situations. These first results highlighted that not all surveillance situations were handled efficiently (e.g., some manikins were not detected after 120 sec, especially when they were far from the lifeguards, when the attendance was high and in deep water).

Perspectives

The present research analyzed a simple, but crucial, variable: the detection time of a submerged manikin by PPLs in a public swimming pool. Our approach therefore addressed a fraction of the significant health problems of drowning but remain essential to consider by PPLs to improve the efficiency of their surveillance. We feel it is necessary to consider what happens during the aerial phase of a drowning incident (i.e., when the individual is still at or near the surface of the water), and after having submerged. Stallman et al. (2017) aimed at a more inclusive set of drowning prevention strategies but remained somewhat far from considering each individual's unique characteristics or the environment specificities in which a drowning incident may occur. A more psychological- and behavioral-based approach such as ecological dynamics should be considered to include the individual–environment coupling as the smallest unit under analysis to perfectly understand this phenomenon. In this perspective, Schnitzler et al. (2018) focused on the cold-shock response following a sudden immersion since many of drowning incidents occur in natural aquatic environments. This is a valuable starting point to teach aquatic environment users physiological, psychological, and behavioral strategies to develop their aquatic competencies to safely interact with water.

Practical Applications

Our study highlighted that redefining lifeguard interventions based on constraint manipulations may optimize surveillance procedures in PSP. From a preventive perspective, regularly manipulating significant constraints such as the ones in the present study may help lifeguards to adapt more easily to their environment as a result developing their perception flexibility for a larger panel of life-threatening situations.

Secondly, it is also important to teach all individuals involved in the PSP that drowning risk management is highly dependent on the dynamic nature of the aquatic environment which impacts the lifeguard's ability to detect an immersed body. Therefore, we have shown that a rapid drowning detection is not exclusively linked to the individual detection capabilities of the lifeguards, but rather it emerges from the tight coupling between the lifeguard perception and his/her working environment.

The variables selected in the present research ought to be viewed as essential determinants of the detection performance, and lifeguards should favor a high surveillance position relative to the water surface level (e.g., surveillance platform positioned as close as possible to "risky areas" especially for deep pools), but not too far from the pool side. This objective could also be achieved using a standing position from the ground if the surveillance is actively performed while walking. Hence, we strongly recommend that walking lifeguards on the pool deck can increase the chances of detecting a submerged body. These strategies may limit the prevalence of drowning, but the human surveillance might also be assisted and completed by computer vision and artificial intelligence technologies (Boeglin, 2014) that could be insightful in the eventuality of a visual omission by lifeguards.

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Endnotes

[i] In the absence of guidelines regarding the appropriate time for drowning detection in the French context, we referred to the international consensus obtained recently in the framework of this ISO standard. Regarding the use of computer vision system, it must be kept in mind that after the alarm rings, an additional delay of a few seconds is necessary for the lifeguard to make sense of the alarm (perceive it, understand the emergency situation, locate the precise place of the incident, and move to this place).

[ii] According to the regulations, the maximal number allowed (MNA) is the maximal number of persons allowed in the pool facility at any one time. It was calculated by the facility supervisor as a function of the usable surface of the facility. The number of swimmers in the pool at the time of the test was determined as a function of the % MNA of the facility (Table 2). Meetings with the pool managers enabled us to adapt these percentages so that they best reflected the reality of the number