A review of quick-release harness performance in water rescue

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Received 2 October 2012
Revised 8 March 2013
Accepted 21 March 2013

Abstract

Purpose – The purpose of this paper is to consider the performance of quick-release harness buoyancy aids in water rescue.

Design/methodology/approach – The assumption is questioned that the performance of water rescue harnesses, in what is perceived as benign, low-flow conditions (<1.85 km/s) is acceptable. Increasingly, rescue personnel are deployed to flooding events during which low-flow, but high-hazard conditions may prevail. A range of commercially available buoyancy aids manufactured in the UK were tested under "real world conditions" and the nature of the release rated.

Findings – The primary data illustrate that 25 per cent of releases where incomplete in low-flow conditions. By analogy a karabiner in a rope rescue system with a 1:4 chance of failure would be unacceptable. Consequently, harness testing, design, manufacture, use and deployment may all be in need of reconsideration if the harness is to remain suitable for its current deployment.

Originality/value – A group of international experts from the USA, Europe and the UK have reviewed the findings and highlight possible reasons for these failures. These comments form the basis for research in future papers.

Keywords Live bait rescue, Personal floatation device, Quick-release harness, Water rescue

Paper type Viewpoint

Quick-release harness performance in low-flow conditions

Increased emergency service response to flooding incidence worldwide has in turn resulted in increased deployment and training of personnel in water rescue. Along side, an increased scrutiny of the techniques and equipment used in that response has resulted in new avenue of research, that of water safety and rescue. As an important aspect of an emergent field (swift water rescue research) it is surprising that the performance of quick-release harness (QRH) has not been formally investigated. To date much of the practice, design and technique relating to the QRH has been based on anecdotal evidence from practitioners (J. Gorman, 22 August 2012, personal communication) with little empirical evidence-based detail available in the literature. Swift water rescue has relied heavily on techniques and opinions gleaned from the recreational and commercial white-water fields. One such item of equipment is the integral QRH that is worn by many response personnel. However, the greater breadth of incident types, level of training and experience of rescuers and performance of equipment may all be responsible for an increased reporting of incidents in which QRH have either failed to or spontaneously release in training and in real life deployment.

The authors would like to acknowledge the support of Rescue 3 (UK), Palm Equipment International, Peak Equipment, Surequip and Nookie. The project was supported by the University of Central Lancashire Knowledge Transfer Initiative and the Livesey Research Scheme.

International Journal of Emergency Services
Vol. 2 No. 2, 2013
pp. 141-154

2047-0894
DOI 10.1108/IJES-10-2012-0041

P. O'Sullivan, (5 June 2008, personal communication) and T. Rogers (3 May 2012, personal communication).

Integral QRH have been an essential feature of personnel floatation devices (PFDs) since the 1980s (Ray and Walbridge, 1995) and have been used in water rescue and are now used by professional rescue services throughout the globe to facilitate water rescues in a wide range of conditions (Bills *et al.*, 2011).The QRH is considered a fundamental component of personal protective equipment (PPE). Increasingly multiple agencies are reporting the adoption of a universal tethered wading technique utilising a QRH as standard operational procedure (SOP). However, the QRH's evolution as a "white-water" harness may not make it suitable for use in low- and zero-flow conditions. The increased deployment of rescuers to incidents with low or zero water flow conditions and the adoption of SOPs raises the question of the suitability of the harness for the conditions encountered (Fire and Rescue Services Act, 2004). Critically, QRH "must reliably release under a relatively light load right through to an extreme loading" (Ferrero, 2006, p. 132) in order to separate the rescuer from the line should a rescue attempt fail or the rescuer become endangered.

The capacity for the rescuer to release from the tethering line in the event of a problem with a rescue is a critical "link" in the safety chain. This capacity is integral to the safe deployment of personnel and is a fundament component in scene safety and security.

This study investigates two related research questions:

RQ1. Does the QRH that is integral to PFDs operate effectively in low-flow conditions? (Velocity is <1.85 km/s, National Fire Protection Association (NFPA), 2009).

RQ2. Where should further research focus in order to optimise performance and use of QRH harnesses?

Accordingly, this positional paper will review primary data from field tests that may enable focused secondary research in the future and will seek to establish the validity of anecdotal evidence in this instance; namely, is there really a problem? Possible avenues for further investigation will also be considered later in the paper by reviewing the findings of focus group of experience water rescue instructors. Pending these finding further avenues of research will be identified.

In providing a primary review, the user groups are outlined, historical development of these harnesses, design of current QRH, current manufacturing standards, give some examples of use and consider the potential problems associated with releases under low-flow conditions. Data will be presented from a series of field tests and the focus group discussion of those results outlined. This will form the basis of secondary investigations over the coming year.

User groups

Rescue personnel (voluntary and professional) are trained in the use of PFDs with integral harnesses (Department for Environment, Food and Rural Affairs, 2011). This training is primarily as a method of achieving a rescue in flowing and standing water. In addition to the rescue role, the PFD/harness combination is utilised as a method of ensuring personal safety by employees in the work place. Organisations including Fire and Rescue Departments, Ambulance Services, Police and Mountain Rescue Teams, the Royal Society for the Prevention of Cruelty to Animals, the Environment Agency and Royal Life Boat Institution (O'Sullivan, 8 May 2012, personal communication and Heald, 3 May 2012, personal communication) all fulfil response roles in the UK and have remits to respond to water-related incidents if requested. Following significant inland flooding events in the UK during 2007 (Environment Agency, 2007) the Knight Report (2008) outlined a vision for enhancing the capability of the Fire and Rescue Service when attending flooding events. Specifically, Knight (2008) detailed the proper use of PPE and training of personnel responding to flooding incidents. In similar fashion, Pitt (2008) set out the need for the UK Government to play a lead role in the establishment of a national framework for flood response. Both these reviews, coupled with the clear increase in such incidents served to raise the issues of the suitability of PPE for urban and sub-urban use to a strategic level and the relevance and suitability of the techniques and equipment currently being deployed.

A history of development

In the 1960s, European white-water kayakers adopted generously sized alpine mountaineering harnesses for river rescue purposes (Ray and Walbridge, 1995; Rowe and Wardle, 1980). These harnesses were not designed to release under load should the wearer need to disconnect from the line in the water. This potentially placed the rescuer at risk of entanglement[1] or entrapment[2] and consequently, a QRH utilising a plastic cam buckle was developed as a "stand alone" item that could be worn over the top of a PFD (Rowe and Wardle, 1980; Crosslin, 2012). In the 1980s manufacturers began production of dedicated QRH as an integral part of PFDs (Ray, 1998). During the 1990s standards developed (cf. International Standards Organisation (ISO), 2006) that set clear parameters for performance, this in turn led to the inclusion of a back bar, adjacent to the cam buckle, to increase the load-bearing capacity of the QRH.

Current design: harness personal floatation device combination

A PFD is a vest or jacket suitable for water rescue, consisting of shaped, closed-cell foam sections positioned against the wearer's torso (illustrated in Figures 1 and 2). PFD's enable the wearer to swim in a conventional facedown (front-crawl position) that would otherwise be impossible in a life jacket (ISO, 2006). This differentiates the life jacket, from the buoyancy aid with integral QRH used in rescue, however, both are PFD's, for this paper the term PFD referring to the later buoyancy aid with integral QRH is used.

In addition to the buoyancy of the jacket, there is generally also a webbing structure around the outside of the buoyant material that performs multiple functions including the stowage of ancillary safety devices (knives, whistles, prusik loops, etc.). The webbing also introduces a structure and form to the PFD during a rescue, although the details of design vary between manufactures. In addition to these generic features, rescue PFD's also provide the aforementioned QRH that provides an anchor point for a throw line (tethering line)[3] via a dorsal attachment point.

Manufacturing quality standards

Both the European (ISO, 2006) and American standards (Underwriters Laboratories Inc, 2008) describe criteria that are evaluated by laboratory testing. These include a criterion that the release mechanism shall require no more than 110 N to release the device (known as the 25 lb test in the USA). The harness is also subjected to a strength test, during which the release mechanism must not spontaneously activate at 1,100 lb

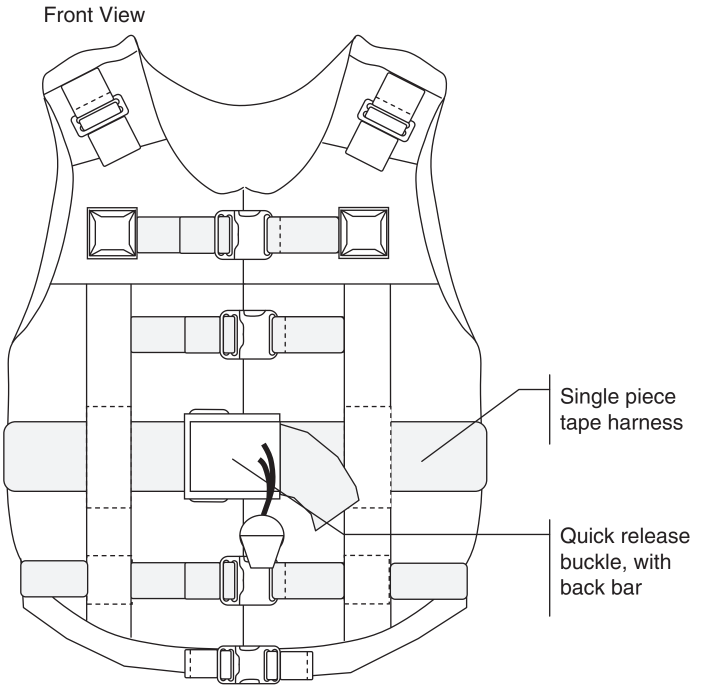

Figure 1.
Front view of PFD with quick release harness

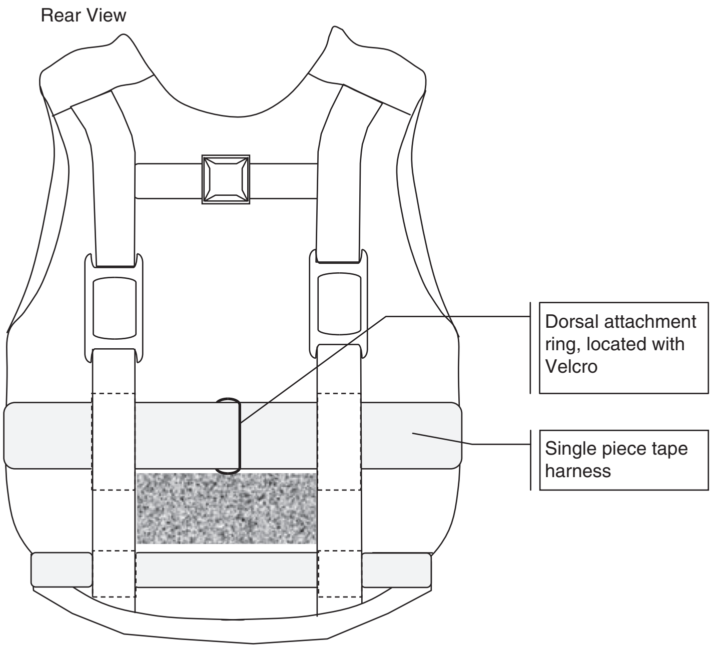

Figure 2.
Rear view of PFD showing dorsal point of attachment of harness

(4.9 kN) in the USA and a range of forces up to 2.5 kN in the UK. These laboratory tests verify the harness as fit for purpose.

The standards by which PFD manufacturers are governed dictates that QRHs should be operable under relatively high-water flow conditions. In all conditions the force of water applied to the dorsal surface of the wearer is generally responsible for the full release of the harness from the anchor system, and a high flow (and high force) will more reliably deploy the release mechanism successfully. The lowest force criterion that a QRHs should function reliably is 250 N (ISO, 2006).

Examples of current use

Typically, in the UK the rope end of the throw line is held/belayed by a rescuer or secured to a point on the bank with the bag end being attached to the QRH of the PFD. This leaves the rescuers hand free to facilitate the rescue and in the event of difficulties to activate the release, thereby leaving the wearer with their buoyancy aid, but no longer being attached to the base point or line.

The harness is primarily used for "live bait" rescues (Bills *et al.*, 2011, p. 8; O'Sullivan, 2002, p. 327), and can be used for rescues in different configurations depending on the specifics of the rescue being attempted, including a tethered swimmer (live bait rescue), a "V" lower, a "Y" lower, plus various entrapment rescue and belayed wading rescue (Bills *et al.*, 2011; Ferrero, 2006; Ray, 1997). All of these techniques, although developed to resolve a specific rescue scenario, share:

- the inclusion of the rescue buoyancy aid (with harness) as integral to the system;
- being clipped into a quick-release system that will function while being loaded by the flowing water,
- multiple safety back up in the event of a release; and
- a dorsally located attachment point at approximately shoulder blade level to ensure a "defensive" swimming position if require but also allowing effective swimming and functioning as a rescuer (Ferrero, 2006, p. 136).

Release from the rope reduces the risk of entrapment or entanglement and dependant on a load being applied to the QRH. However, it is equally recognised that, in condition of low or zero flow such as a deeply re-circulating hydraulic features or a strong eddy-fence, there may not be the force required to ensure adequate release (Ray and Walbridge, 1995).

Potential problems in low-flow conditions: what is the problem?

Reliable release during low-velocity conditions is critical given the increased deployment of rescues to low-flow environments (cf. Fire and Rescue Services Act, 2004). More general concerns are reflected by Ferrero (2006: p. 133) who suggests that the design of quick-release systems must be finely balanced so as not to release spontaneously, thus putting the user in a potentially perilous position, while releasing reliably should the user require it in a broad range of conditions. The limitations of current harness design in low-flow conditions are increasingly recognised, with authors encouraging "cautious experimentation" to develop the user's understanding of the limitations (Ferrero, 2006, p. 133) or the need for manipulation of the system to facilitate a release in the event of a failure. Investigation by Fowlkes (2012) suggests that the force proportional to the water flow may vary between 53 and 213 N to achieve release.

The investigation

Based on these various considerations, it is considered to be important that the variables encountered during the test are realistic, involving factors or combinations of factors that may affect the performance of the QRHs. Using these ecologically valid challenges, representative force values need to be determined.

Reliability, validity and repeatability are critical to establish academic rigor, as is the trustworthiness of the results to the rescuers who use the harness in the field. In this respect, a balance must be achieved between rigor/repeatability and value to the end-user. Additionally, a genuine investigation must consider meaningful samples of equipment. Accordingly, samples of commercially available rescue harness PFDs that are in use in by professional rescue teams throughout UK were evaluated.

O'Shea (2006) identified indicative force values induced on stationary objects held in river flows. The force induced by the water will be proportional to the change in momentum of the water due the surface area of the object incident to the flow. The water pushing upon the object will equal the pull in the ropes holding the object in the flow. While this method is attractive as it is straight forward, it is only applicable to objects incident to the water flow and relies on linear flow rather than the turbulent flow encountered by practitioners in the field. For these reasons, real world testing during which the profile of the participants' dorsal surface is presented to turbulent flow is adopted.

Taking the approximate[4] surface area ($0.11\,m^2$) of the PFD presented at 90 degrees to the current flow gives an indication of the required river speed of 1.5 m/s to induce a force of 250 N on the participant (O'Shea, 2006). This is the lowest force in a range of 250-2,500 N described in ISO (2006). The NFPA (2009) define swift water as having a velocity $\leqslant 0.5$ m/s, clearly much lower than the river speeds anticipated by either the International Standards Organisation or Underwriters Laboratories Inc.

Method

PPE, safety and ethical considerations

Testing the operation of the harness in context exposes the participant to a degree of risk. Consequently, participants where selected on the basis of their qualification and experience together with familiarity with the harness and experience in the water. These characteristics both enabled qualitative data to be gathered and aided the security of the participants.

Following risk assessment, participants were equipped with and donned according to the manufacturer recommendations, water rescue boots, dry suit, knife and helmet in addition to the PFD. In addition, a method of signals agreed to indicate a need for assistance. Two other instructors were on standby to assist if required and the V-rigs constructed to be releasable in line with accepted water rescue practice in the UK. Participants agreed to take part in the testing and for their data to be used although their identities to be withheld. The manufactures agreed to provide equipment on the basis that results were anonymised and that detail of models and designs of PFD were withheld.

Test site and calibration

For the purposes of this paper a test site with a water speed of 1 m/s was used.

The test site was located in a river channel 100 m downstream of a British standard broad-crested weir (International Standards Organisation, 2008). Level and flow data were recorded every 15 min at the weir to ensure accurate calibration of the site.

Proximity of the test site to the point of discharge ensured accurate measurement at the test site.

The site comprised of a gravel bed earth embankments with some rock armouring at key locations. Due to the nature of the channel the flow type at the test site was turbulent slow flowing being representative of the conditions experienced by water rescue personnel.

A water velocity profile survey was conducted using a RDI Stream Pro Acoustic Doppler Current Profiler and tag line. An accurate model of discharge and surface water velocity was calculated from data collected using Hydrologic software (WinRiver). Repeating the profile analysis for a range of discharges (1-12m^3/s), cross referencing with the location and discharge, the water velocity for each of the test series events was calculated and recorded.

"*In water*" *testing*

The approach for determining the force induced by moving water on objects positioned by ropes has been established by Onions (2012) in his masters thesis. Onions presents the case for capturing data under real world conditions using appropriate equipment in preference to mathematical modelling. In this instance, the participant was positioned consistently mid-stream in the flow by a V-rig. A Tractel™ universal column load cell was connected in series with one of the V-rig anchor legs. Data were transmitted with a 30 m length of data cable to an in-line signal amplifier. Trigonometric evaluation of force vectors demonstrates that measuring the load in a single anchor leg would be identical to that placed on the participant's dorsal point of attachment when the angle of the V-rig tends to 120 degrees (Brown, 2000; Ray, 1997). The load cell, cable length and amplifier were calibrated by the manufacturer as a combined unit using a five-point calibration procedure. A data translation analogue to digital signal convertor was used to transfer the mV signal to a laptop PC and was exported to Microsoft Excel. The manufacturer's calibration curve was used to convert the mV signal to force (N).

The participant adopted a passive floating position in the flow and was instructed to release their chest harness. Force (N) against time (s) curves were produced in MS Excel using the chart function. The time for complete separation from the harness, was determined from the force/time curve profiles.

The release events were categorised as successful or unsuccessful. A successful release was described as a complete separation from the V-rig, without impediment within ten seconds (ISO, 2006). An unsuccessful release was one in which either separation from the V-rig was incomplete, exceeded ten seconds or encountered impediment that was noticeable by the participant or required action on the participants' part.

In the cases of unsuccessful release the participant was asked to describe the nature of the release using a Likert scale. The participant was questioned verbally immediately after the event and presented with a "prompt card" outlined below:

- Category 1: the harness released with friction being experienced by the participant in the form of juddering, vibration or a faltering release within ten seconds.
- Category 2: the harness released with assistance from the participant in the form of an intervention following the release. The participant intervened by manually pulling the webbing through the cam buckle, adjusting the release buckle. However, release occurred within ten seconds.
- Category 3: failure to separate from the V-rig with in ten seconds.

In addition to this categorisation the participant was requested to speculate on reasons for the unsuccessful release. The participants in these test where experienced water rescue instructors, having held international qualification for over five years and have over 10,000 hours of teaching experience.

A sample of seventy release events was performed for a range (six models), of commercially available rescue PFDs and the results were tabulated with the corresponding force data, timing data, category and comment from the participant.

An independent focus group of ten participants was formed to review the results. Consent was given and members of the group selected on the basis of their qualification, reputation, experience, expertise in the field and non-participation in the field tests. Specifically, being qualified water safety and rescue instructors with over five years experience, being current and willing to take part in the investigation. Due to the international nature of the group, members were encouraged to participate via a range of communication methods including structured interview, semi-structured interview, e-mail, on-line fora (*Swift*H_2O) and informal discussion. The group sat on an informal basis for six months and was chaired by the authors. The resulting feedback from the interviews was transcribed and thematically analysed.

Results

In total, 72 tests were conducted. Of those tests 53 where categorised as successful and 18 as unsuccessful. Of the 18 unsuccessful releases, six were categorised as 1, six were categorised as 2 and four were categorised as 3. Mean and standard deviation were calculated for load (N) and time (s). Results are summarised in Table I.

Table I.
Further evaluations of the 17 unsuccessful releases

Descriptor	Number	Load (kN)	Time for separation (s)	
Category 1: mean load 0.09 kN, SD 0.03 kN, mean time 4.5 s	6	0.07	5	–
		0.11	4	–
		0.11	5	Caught on hot knife termination
		0.05	5	Faltering then released
		0.10	5	Faltering then released
		0.15	3	–
Category 2: mean load 0.11 kN, SD 0.04 kN, mean time 3.6 s	6	0.06	5	–
		0.11	3	–
		0.11	7	Over-cammed buckle
		0.17	2	–
		0.05	3	Webbing wedged in corner of buckle
		0.14	2	–
Category 3: mean load 0.09 kN, SD 0.02 kN	4	0.08	20	Wearer “bounced” to released
		0.11	15	–
		0.06	10	–
Mean time 21.0 s		0.09	40	Webbing folded and jammed

Focus group discussion and results

The focus group concluded that possible reasons for unsuccessful releases could be grouped as three clusters; hardware, use and environment. The clusters where further sub-divided and incorporated into the list entitled.

The initial testing and analysis indicated an inconsistent performance of harnesses releases in low-flow conditions. Of 70 test releases 19 failed to release with an uninhibited separation of harness and line. This was considered to be unaccepted by the focus group.

The extent of the problem?

Without exception all focus group members had first hand experience of failures with QRH. Selleck (2012) reported that "the second time" and Crosslin (2012) " numerous times". These failures fell into two groups; spontaneous releases in high-load conditions and non-releases in low-flow conditions. The incidence and regularities of failed releases was sufficient for three instructors in the focus group to have developed and teach solutions to the potential failure. While a consensus was not achieved regarding the most appropriate solution the authors considered that such remedial action was significant in considering the significance and regularity of these incidents. Waller (2012) advocating "Clip a locking karabiner into the cord loop that connects the red ball to the plastic buckle and lock it on shore" and a "a multi step release. Grasp the ball, pull the ball away from you and then pull it to the left". M. McLay (2012) preferring to ensure success by "[…] selecting mainly high energy water" using a heuristic rule; "above what you can wade in" to aid in venue selection and as guidance for personnel when deployed. Parker (2012) concurred, "The sort of environment I'm trying to find is that of a fast jet of water". Hargatt (2012) proffers a solution to avoid the issue of altering the threading (possibly against manufactures recommendations). Perhaps the critical point is not the actual solutions found, but the number of incidents that have obliged instructors to seek out solutions! (cf. Ferrero, 2006, p. 133).

Hardware; harness design and manufacture

PFD/tape/buckle interaction

With in the group deign, manufacture and testing of the QRH was considered to be a main cause of non-release. Crosslin (2012) stating "[…] the flat webbing and the buckle not being a good match" and "[…] rotation of the webbing as it enters the QRS" These statements are supported by O'Sullivan (2012), Ben Waller (2012), Matt McLay (2012) and Hargatt (2012) though only Hargatt (2012) suggests this is a "back bar" problem. The previous commentators suggesting the issue arises at the plastic cam buckle.

Manufacturers have experimented with combinations of tape and buckles to ensure the CEN standards are met at the time of testing Onions (2011) highlights a similar problem between prussik and rope interaction. The focus group highlighted problems in quality control that focused on the consistency and tolerances of components in addition to the interaction of components.

Manufactures supplied eight different webbing types to the research team that varied in dimension, flexibility and friction and five different buckle sizes and types. These differences where marked between different manufacturers but also within manufacturers who provided outwardly identical webbing and buckles but on direct observation and comparison different in function and behaviour.

The matter is further complicated as it is not always clear from the design if all three components (buckle, back bar and tape) are to be used in the threading configuration (O'Sullivan 2002). Hargatt (2012) comments on complications with the threading of the QRH system and general complexity with the PFD leading to confusion in use.

Different samples have different instructions for threading. This has led some authors (Ferrero, 2006, p. 133) suggesting that practitioners needing to find pragmatic solutions to real world problems. This ambiguity is unwelcome to both the rescuer and instructors who are unable to give a definitive description how to thread the harness (O'Sullivan, 2012).

Gorman (2012) raises concern at the position of the dorsal attachment point suggesting that this varies between manufactures and also when the PFD is donned by an individual particularly if missized. Gorman also proposed that design features of the PFD that ensure a high-dorsal point may increase friction between the webbing and PFD.

Length of tape

A recurrent theme amongst the group was the length of tape passing through the buckle following release. McLay (2012) stating "[…] it all relates to the length of tail" Fowlkes (2012) postulated that the greater the length of tape passing through the buckle, the greater the chance of jamming, this is considered a significant issue by manufacturers (PFDMA, 2008). It was felt that the lack of understanding about tape length was unwelcome. One manufacturer advocated that the tape is trimmed to an optimum length to ensure a limited amount of tape need be drawn through the buckle post-release. This is advocated during training (Rowlands, 2012; O'Sullivan, 2012; McLay, 2012; Parker, 2012). O'Sullivan (2012) makes comment the users do not always take this step or may be discouraged from taking this step if the harness has multiple users or fears of invalidating manufacturer's warrantees. Conversely, Parker (2012), commented on the practicality of trimming the webbing, as anecdotally the burs created by poor trimming may be the cause of jamming on an individual PFD.

However, length may not be the only factor at play here both O'Sullivan (2012) and McLay (2012) and Rowlands (2012) comment on the potential for snagging and twisting as a consequence of the tape being moved in the eddy formed down stream of the rescuer. McLay (2012) suggested that webbing length is not the problem and that the behaviour of the webbing in the eddy created by the rescuer McClay advocated and practiced a careful stowage of the excess webbing. This "tucking away" is a practice frequently observed in recreational use as a way to accommodate excess webbing lengths that accompany not trimming. Rowlands (2012) conjectures that this relates to the fit of the PFD and resultant position of the dorsal attachment point and therefore QRH buckle on the chest, notably below the water level. The criticality of correct sizing, donning and fitting of the PFD is alluded to by Selleck (2012). Conversely, Rowlands (2012) comments on the problems as associated with larger rescuers. Fowlkes (2012) also makes comment on the position of the belt across the torso as a critical component in the QRH.

Additionally; Fowlkes (2012) conjectures that the friction between the tape and the PFD its self may also be a contributing factor, though no other contributors commented on this potential. Fowlkes goes further and suggest that the number of loops the belt feeds through on the PFD act to hold the webbing in contact with the PFD, thus increasing the friction after release. Fowlkes also suggests belts should be checked frequently implying that the nature of the tape and amount and type usage may also be significant in performance.

Environment

All focus group members recognised the need for a load in the system to facilitate the release. As previously mentioned, this manifests during venue selection (McLay, 2012; Rowlands, 2012), O'Sullivan (2012) and Parker (2012), however, opinion that the increased deployment to low energy environments raises the question of design appropriateness. Logically it follows that a question must be raised as to the suitability of the CEN and UL standards. Hargatt (2012) states and was clearly irritated, "This is a problem that we invented when we asked for blow out tests. I'll say it again! We need to be smarter and know what we're getting into before we place our selves in dynamic water" which echoes Rowland (2012), McLay (2012) and Ferrero (2006, p. 133) on the need for users to be conversant with the capabilities of the QRH and the environment in which it will function safely. Hargatt takes issue and also raises the need for judgement in harness use. O'Sullivan (2012) and Gorman (2012) argue a similar stance regarding the standard from the European perspective (CEN).

McLay (2012) and Rowlands (2012) identified a need for the tuition of judgement skills in QRH use in addition to the technical requirements in educational classes. Going beyond replication into application of the techniques taught. The broader issue of operator error was felt by McLay (2012) and Rowlands (2012) as significant in training. The impact of the water rescue environment on inexperienced rescuers, complexity of some harness/PFD designs (Parker, 2012) all compound problems in a training context.

General discussion

Awareness of the limitations of the QRH appears as explicit knowledge amongst water rescue specialists. Nevertheless, for the present purpose it would seem reasonable to suggest that lack of explicit guidance on these limitations may prove, at best, an inconvenience but in certain circumstances as significant hazard to the inexperienced rescuer deployed to an unfamiliar incident.

From the focus group, key themes emerged of the limitation of the material and design of current QRH, sizing and fitting of PPE in particular the position of the harness and its customising to the individual, the judgement skills require to use the QRH safely and effectively and the environment in which the QRH is deployed.

While it is evident that Rescue PFDs sold within the European Economic Community and the USA are subject to rigorously controlled laboratory testing, there is conflicting anecdotal and empirical evidence from the American Canoe Association (Fowlkes, 2012), Rescue 3 Europe, Rescue 3 International, Rescue 3 UK (O'Sullivan, 2012) and this study that PFD QRHs do not always perform as well in the real world context as experienced in the laboratory.

The change in deployment, production standard requirements both in Europe and the USA, and the resultant modifications to the harness (namely the back bar to improve load-bearing ability) may have inadvertently affected the capacity of harnesses to release at lower loads. These changes may be placing the rescuers at greater risk in, what are perceived by inexperienced rescuers, to be more benign environments, characterised as low-flow conditions.

Conclusion

Circumstances of standing water will also present a risk of incomplete release should one be required. Against all of these situations therefore, the capacity of the harness to release in zero- and low-flow conditions appears to be critical for the professional and highly desirable for the recreational white-water enthusiast. This evidence suggests releases in these conditions are unreliable and inconsistent raising concerns for experienced and inexperienced users alike. We consider that experienced users may have the judgement skills required for safe application; however, inexperienced users following poorly considered SOPs may be at a higher risk. The imperative being improvement to harness design, use and training that includes the judgement skills required. This will form the basis of a third paper in this series.

This study investigates two related research questions:

RQ1. Does the QRH that is integral to PFDs operate effectively in low-flow conditions?

To which we conclude that the QRH does not operate effectively:

RQ2. Where should further research focus in order to optimise performance and use of QRH harnesses?

This research suggests further investigation into the design and manufacture of the harness; the tuition and the techniques employed during use are required. This will focus on the materials used, optimising load within the system and action by the user.

The results illustrate that at lower loads (as specified in current CEN and UL tests) the performance of the QRH is inconsistent when used by experienced personnel. They can be attributed anecdotally to manufacturing, environmental, operator and training causes and will require further research.

The lower performance limits laid down in the current standards (CEN, 0.25 kN and UL, 0.22 kN) both require a successful release at the loads experienced in this test, inconsistency in this performance begs the question is the harness, in its current form, meeting these requirements and that of the professional rescuer in terms of its consistency and breadth of operational loads. Further research will be required to consider development of QHR design and manufacture to achieve a consistent performance in a broader range of conditions. Along side any "engineering solution", investigation of the judgement and practical skills associated with real world deployment will be required and will provide a further avenue for research.

Notes

1. Entaglement; the "snagging" of rope in/on an obstruction that may cause the rescuer to become forced to the river bed by the action of the flowing water.
2. Entrapment; the snagging of the body or other items belonging to the rescuer that holds them in the water.
3. Throwline; a brightly colored bag containing floating line of around 8 mm diameter that can be utilised in water rescue.
4. Based on an average of the participants taking part in the test.

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