Improving the performance of swift-water rescue quick release harnesses

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Abstract

This paper considered the effectiveness of empathic design modifications to quick release harness design. It was found that the critical element in effecting a rapid and efficient release was the tape length distal to the buckle/back-bar components. We have concluded that the length of tape pulled through the buckle and the loading of the buckle/ tri-glide are critical to ensure an effective release. Physical separation of tape and buckle mechanism when the harness is released is crucial to the effective release. We then considered the problems this may pose in multiple user situations such as 'call out' teams or training use and we propose that the adaptation utilised in the research harness to facilitate testing may provide a simple and low cost solution to the multiple user problem allowing easy adjustment of the harness to ensure the separation of buckle and tape on release. We conclude by outlining the design adaptations and recommendations for the training and use of the quick release harness and make recommendations for the training of QRH use.

Key words: *Quick Release Harness, swift-water rescue, water rescue,*

Introduction

This paper considers the effectiveness of empathic design modifications to the quick release harness used in water rescue. This research firstly outlines the problem, as raised by Onions and Collins (2013). Secondly; outlines and conducts a series of tests on a range of different harness designs and threading configuration and finally will identify features that improve the performance of the quick release harness (QRH). The research discusses the implication for use and concludes by outlining design and technique adaptations to the harness that may address the issues raised.

Literature Review

Problems with Quick release Harness performance

Reflecting the lack of empirical research into QRH performance we have utilised our previous work in this field, c.f. Onions & Collins, (2013). In our previous paper (Onions & Collins 2013) we highlighted inconsistencies in the performance of QRH and concluded that 25% of releases had the potential to or did actually jam and fail to release. In that paper we tested a range of commercially available QRH and interviewed fifteen expert and qualified swift water rescue instructors from the United Kingdom and United States to identify possible reasons for the poor performance. This paper follows directly from that work by testing a series of empathic design adaptations and reflects feedback from that user group.

Three aspects of the QRH performance and its use emerged from the discussions; firstly, the action of the rescuer immediately after the release is activated. Secondly, the interaction of the components in the QRH, and finally; the judgements required in the effective use of the QRH are considered. This paper will focus the first and second considerations; a subsequent paper will explore the broader issues of professional judgment and decision-making in QRH use.

Current design of PFD and QRH

Current PFDs consist of pre formed buoyant foam held within a jacket or vest that is worn by the rescuer (Figure 1). A PFD differs from a life jacket, International Standards Organisation, (2006) in that it enables the wearer to swim in a conventional facedown (front-crawl position) and protects the back while swimming defensively (feet downstream, face up) Rescue PFDs have an integral QRH around the outside of the jacket although exact details of design vary between manufactures. This QRH generally contains a 40-50 mm tape that passes around the chest and back at a mid thoracic level.

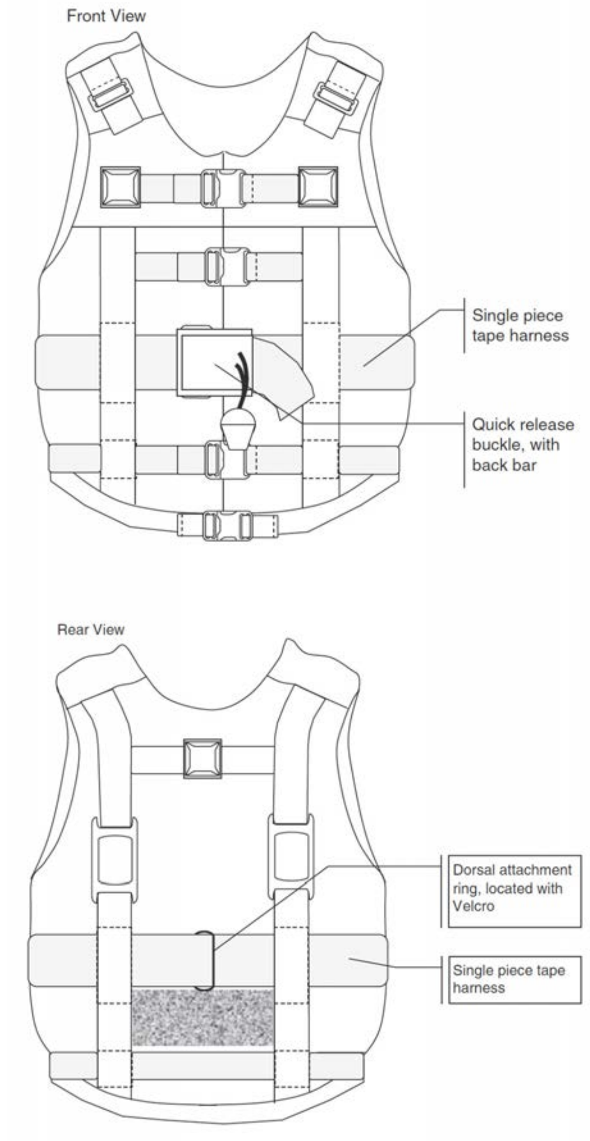


Figure 1: Front and read view of PFD illustrating position of QRH in current PFD design and components of QRH system. Reproduce with permission from Emerald publishing, Onions, C. & Collins, L. (2013). Performance of quick release harnesses in swiftwater rescue. International Journal of Emergency Services, 2 (2). 141- 154

This tape has a dorsal attached mid back and a quick release mechanism on the front that can be activated by the wearer and release the tape. The dorsal attachment point on PFDs is mid thoracic spine and differs from the higher (upper thoracic spine) attachment found on working at height, fall arrest harnesses (c.f. International Standards Organisation, 2000).

The release mechanism is a crucial element of the QRH design; it enables the wearers to separate themselves from the tethering line, used during a rescue, in the event of entanglement or an excessive pressure on the wearers' torso the harness can be released and the rescuer either self rescue or be recovered by the down stream safety. The QRH release has to be able to operate in a broad range of conditions and loads; within the load range (250N – 2500N) the system is required firstly; to hold (be secure) and secondly to be able to release in under 10 seconds (International Standards Organisation, 2006; Underwriters laboratory Inc., 2008).

To address the maximum load capabilities (2.5kN) the QRH manufactures include a 'tri glide to the release mechanism that holds the load via a *capstan effect* (Attaway, 1999) with the releasable buckle holding the tape 'locked' to the tri-glide. When the releasable buckle is activated the capstan effect is reduced on the tri-glide and the tape can be pulled from the mechanism by the force of the water on the rescuer. This upper limit may benefit from further research as users anecdotally report spontaneous releases (Onions and Collins, 2013) with some buckling configurations and concerns regarding the judgements required in selecting to utilise the tri-glide under low flow conditions. Equally, concerns regarding the capacity of the rescuers body to withhold the high loads around the chest must also be considered. Bierman, Wilder and Hellems (1946) historical research conducted in the Second World War identified that the compressive forces (similar in range to those described by ISO standard) diminished thoracic respirations (breathing) and effected pulse pressure causing bradycardia (heart function). Both may bring into question the value of 2.5kN upper limit in the standard requirements however the upper limit discussion will fall outside the remit of this paper.

Given the increasing use of this QRH as an adjunct to water rescue in low energy/ force conditions (Ray, 1996, 1998), its potential inclusion in standard operating procedures and its 25% failure rate (Onions and Collins, 2013) in those conditions there is an imperative for investigation and improvement of the harness, its performance and use. Evidence based on empirical investigation will benefit deploying agencies, rescuers, trainers and manufacturers.

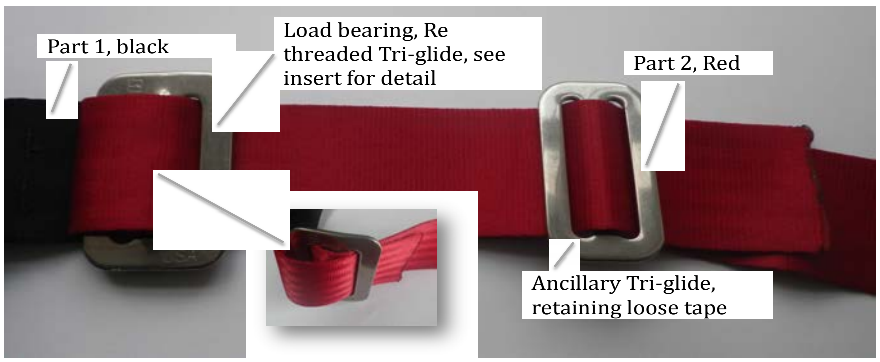
This paper will test a range of modifications to the QRH reflecting our initial paper and identify a range of solutions that could be applied in the field. In this respect we will focus consideration on the action of the rescuer immediately after the release and the operation of the harness during the release.

Method

A single design of personal floatation devises (PFD) was utilised and supplied by a UK manufacturer. The supplied 50 mm QRH was removed from the PFD but no other alteration made to the fabric of the PFD. The PFD was sized and donned in accordance with the manufacturers recommendations and an adapted harness retrofitted. The harnesses under test utilised the same release mechanism as the original harnesses but was threaded in a variety of different configurations, dependant on the test requirements.

Adaptation to QRH

As stated, the adapted 50 mm QRH functioned in an identical manner to the original harness with two modifications for test purposes. Firstly; the test harness was cut into two parts. The first part; Buckle/ tri glide, 25 cm of tape at this point an adjustable/load bearing buckle was added. A second part was made of a single length (150 cm) of 50 mm webbing. Part two; separate tape which continued from the adjustable load bearing buckle, around the body returning to the quick release mechanism. This tape could be adjusted and threaded to become load bearing at the *new* buckle. (Picture 1).



Picture 1: Showing load bearing connection of part 1 and 2

To ensure consistent performance part 2 of the harness was constructed of tape manufactured to consistent quality and behaviour. Random samples were selected from a 100 m reel and prepared as individual lengths of tape to form part two of the harness.

Part 1 of the QRH

Part 1 comprised of the cam buckle (A), load bearing tri bar buckle (B). A and B constitutes the quick release mechanism), and the metal three bar buckle (C) to connect to part 2 (as illustrated in picture 1). Part 1 was constructed to a fixed maximum length (25 cm). Two versions, an *active* version; that contained an elastic portion that created 15 cm contraction in the length and a *passive* version without elastication were utilised in this research.

Part 2 of the QRH

As stated part 2 constitutes a single piece of tape. One end of the tape was trimmed at a diagonal and heat-sealed flat in line with the manufactures advice. The other was trimmed and heat-sealed at ninety degrees. This ninety degree cut end could be connected to part one via the load bearing buckle (C) allowing the length of part two to be adjusted and then secured. Each individual tape length was visually checked following each use to ensure any damage or excessive wear could be identified and the tape removed from the test if required.

The adapted QRH was fixed to the PFD as illustrated in figure 2.

Sample Group, Safety and Ethical Considerations.

Following ethical approval a purposive sample group of six participants was selected on the basis of their qualification and experience. Namely being a qualified swift-water rescue instructor with over five years experience. Following a risk assessment and subsequent briefing, participants were equipped with water rescue boots, dry suit, knife and helmet in addition to the PFD/Harness being tested. A down- stream safety back up was maintained, given the location immediately downstream of a dam outflow no up-stream spotter was deployed (one would be required in other settings and is illustrated in Figure 3).

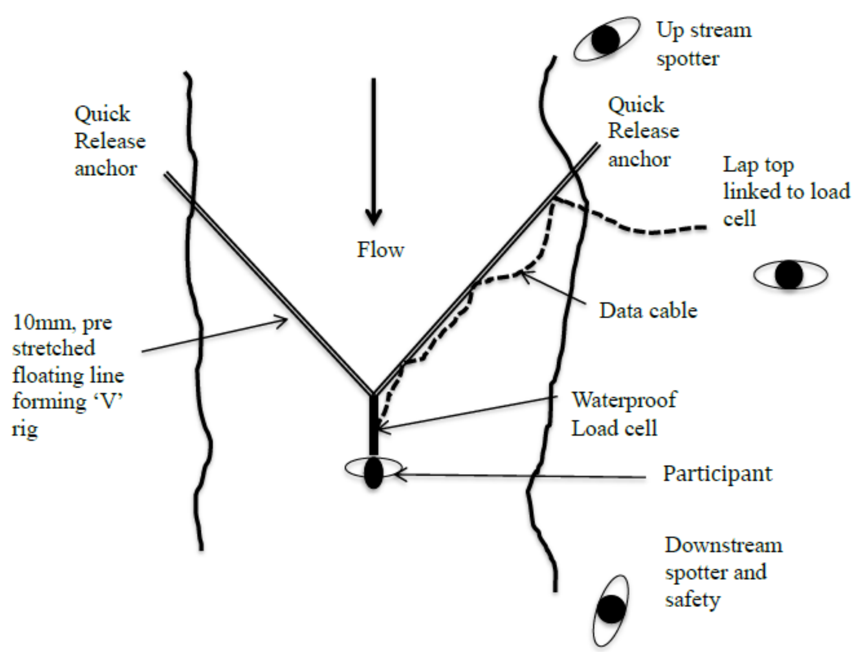


Figure 3: Illustration of V rig utilised in testing

Procedure

The participant was positioned mid-stream in the flow by a pre tied V-rig (Figure 3). A waterproof Force Logic™ universal column load cell was connected in series with the dorsal point of attachment of the participant, and the apex of the V-rig. The load cell was connected with a 20 m length of data cable to an in-line signal amplifier. The load cell, cable length and amplifier are calibrated by the manufacturer as a combined unit using a 5-point calibration procedure. A Data Translation™ analogue to digital signal converter 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).

A series of ancillary tests was completed to establish the effect of changes in body position on loads in the system, establishing the mean length of tape distal to the release mechanism (the length of tape potentially pulled through the release buckle) and the mean load required to separate the Velcro™ locating attachments on the rear of the PFD. These results are briefly outlined prior to presentation of the results in the following section of the paper.

Data collection

A mixed methodology was adopted to generate a rich data source. It was decided not to subject participants to an excessive amount of replicate tests; in preference a broad range of data collection sources was utilised. A sample of 234 releases was performed using a range of different harness configurations.

Force/ Load data Collection

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

Qualitative View of participant

Following each release the participant was asked to describe the nature of the release using a prompt sheet (Table 1) and any other notes recorded. Participants were encouraged to speculate on reasons for the notable events during the test.

Rating	Descriptor	Example
1	From release to separation no notable friction or delay in the process	*A smooth consistent and constant flow of the tape through the buckle.*
2	From release to separation friction and load on the thorax is notable by the participant	*Friction between the tape and buckle is noticeable by feeling rubbing or faltering as the tape pulls through the buckle.*
3	From release to separation there is a momentary delay in the process that rectified without intervention	*Friction between the tape and buckle is noticeable by feeling the force of water, on the participant, increase as movement in delayed and the tape pulled through the buckle.*
4	From release to separation there is a momentary stop in the process that is rectified with out intervention from the participant	*The movement of the tape through the buckle is brought to a stop'. Without intervention the stop is rectified and the release continues.*
5	From release to separation there is a momentary stop in the process that is rectified by an intervention from the participant	*The movement of the tape through the buckle is brought to a stop the participant is required to take a single action to re-establish the movement of the tape through the buckle.*
6	From release to separation there is a clear stop in the process. That is rectified with repeated intervention from the participant.	*A single intervention from the participant is insufficient to 'free the system' and the repeated actions are required to facilitate movement of the tape through the buckle.*
7	From release to separation there is a clear stop in the process. That is rectified by intervention from the bank	*Assistance required recover participant to the bank.* *or* *When loaded in the water the system fails.*

Table 1: Rating scale used to assist participant in quantifying the performance of the harness.

Direct observation of performance

Digital video footage of the front of the harness was taken using a Go Pro Hero-2™ helmet mounted camera during a random sample of releases from each test (S=25). This footage was reviewed at 50% of normal speed; this provided direct observation of the QRH in operation.

Results and Discussion

Ancillary tests

Body position test

The participant was positioned mid flow on the 'V' rig as stated. Once a base line reading was clear the participant was instructed, via an agreed signal from the down stream safety, to alter their profile to the water by extending their arms and legs away from the body into a 'star' shape, this was repeated three times (S= 300) prior to the release test. Following the body position test the harness was released and the participant recovered. During this test a mean load on the harness while the rescuer was passive in the water was recorded (500N, SD 25N). While assuming the 'star shape' a mean load of 725N (SD 25N) on the harness was recorded. Under these conditions this represents an increase of 45% load on the harness by adopting a star shape.

Average Length of Tape Pulled Through the Buckle/ tri-glide

The length of tape on QRH (S-75) on recreational white water kayakers and canoeists was measured (S=75, M= 37.8 cm, SD= 17.34). For the purpose of the test this was rounded up to 38 cm and taken as the average length of tape pulled through the buckle in the event of a release.

Velcro™ release

At the dorsal point of the PFD the manufacturer utilised a 2 x 4 cm *Velcro*™ patch to locate the connecting metal ring, it was considered that the separation of the *Velcro*™ parts would require a load and that this would contribute to the overall load require to release the harness. The harness and PFD was positioned on a test torso and secured. The harness was then removed leaving the Velcro™ and metal ring in place. A digital load meter was attached to the ring and a load-exerted perpendicular to the *Velcro* patch to determine the load, measured to the nearest whole newton (N) required to separate the male and female Velcro™ components (S=45, M= 43N, SD= 0.83). It was concluded that the mean load required to separate the Velcro™ was relevant and that the maximum loads required equated to the positive buoyancy afforded by the PFD. It therefore follows that the PFD could be held under water by the Velcro™ tab in the worst case. It was concluded to remove the Velcro™ locating patches for the test on the grounds that this was a simple method of improving low load release

Harness configurations test

The following five configurations are outlined in table 2. Digital footage of the tests is available at http://youtu.be/ifuLlW0wp9E

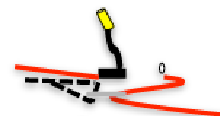
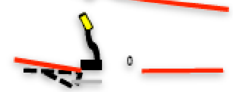
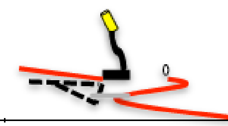
	Part 1	Configuration					Means and S & (SD)		
		Tri - bar threaded	Tail Length (cm)	Diagram	PFD threading	Release mechanism	Load (N)	Time (0.1 S)	Rating (1-6)
1	Passive	Yes	38			Tape	500	12	2.13(1.18)
2	Passive				All Loops		500	11	1.7(1.00)
3	Passive	Yes				Toggle	500	5	1.28(1.01)
4	Passive	No	10				500	5	1 (0)
5	Active	Yes			Dorsal only		500	4	1.07(0.26)

Table 2: Test Configurations and results

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Test 1

The harness was configured as illustrated table 1 the release activated by utilising the tape to open the cam buckle. Direct observation of the release illustrated that during activation the tape forced the buckle and tri-glide against the PFD. The tape remains through the buckle and moves only once the rescuer has released their grip on the tape. This leaves the tape describing a tight 'Z' between the buckle and tri-glide and forced against the PFD, clamping the mechanism to the jacket and maintaining the capstan effect in the mechanism until the tape is released.

Test 2

The test was repeated using the toggle to activate the release. Direct observation indicated the tape moving immediately on activation of the release. The tape continues to describe an 'open' Z as the tape is pulled through the mechanism. This Z created friction between activation and separation however the mechanism was pulled away from PFD and pivoting on the attachment point with the PFD. An increase in performance was noted which was attributed to the reduction of friction and immediate activation noted.

Test 3

The harness was configured and released as for test 2 however the length of tape was reduced to 10 cm. An improvement in performance was noted an open 'Z' shape was described between the buckle and tri-glide immediately following activation. However it was noted that the action of using the toggle and the short tape length physically separated the tape and buckle at the point of release, however tape was still pulled through the tri-glide (this was the distance between tri-glide and leading edge of the buckle, 3-4 cm). Notably no tape was pulled through the buckle by the load of the water following release. The load created by the water at the dorsal point was insufficient to withdraw the tape through the tri-glide and around the PFD via the loops and fabric tubes of the PFD.

Test 4

The test was repeated without the tri-glide and an improvement in performance was noted, however, occasional spontaneous release where observed during the test. The spontaneous release could not be explained via either direct observation or interview. The 'open' Z described test 2 and 3 was noted, as was the separation of buckle and tape noted in 3. It was considered that the tri-glide needed to be included in threading the harness to enable the higher loads required in the test standards. It was considered that this need not be a problem if separation of the buckle/tri glide and the tape could be assured as noted in test 3.

Test 5

Truly zero load conditions are not encountered in any use. The positive floatation of the PFD would always act to provide a load within the mechanism and QRH, this being equivalent to the floatation of the jacket. Examples of low load application include the use of the harness in low-velocity, broad area urban flooding situations where high entanglement potential exists with debris and street furniture and in a swift water context it is also possible to experience deeply re-circulating features/closed features that retain swimmers, but do not possess a water velocity to induce the required load to effect reliable QRH performance. Augmenting the load to ensure separation of tape from tri-glide and buckle in a consistent manner, in minimum time was felt to be a desirable goal. To ensure complete separation (tape from buckle and tri-glide) on the PFDs a shorter length of tape is required. The standards (International Standards Organisation, 2006; Underwriters laboratory Inc., 2008) allow for up to 10 cm slippage in the system, clearly a 5-6 cm length would be impractical and may contribute to spontaneous releases. An elasticated portion was included into the part 1 to ensure a minimum 20 cm of contraction when released. This addition to the QRH assured a separation of the buckle/tri glide and tape without load at the dorsal point. The 'open' Z described test 2 and 3 was noted, as was the separation of buckle/tri-glide and tape noted in 3. Participants commented on the "instantaneous" release but that the tension could be felt around the chest when donning the PFD.

General Discussion

An improvement in QRH release performance has been noted. The greatest effect is achieved by ensuring that the length of tape pulled through the buckle, is short enough to ensure a physical separation of part 1 and 2. For consistency, the research utilised a single design of PFD, as a consequence the results cannot be transferred directly to other designs. Namely, the exact length of webbing will be dependent on the detail of the manufactures' PFD construction. Specifically the position at which the QRH is secured at the front of the PFD and the relationship between the length of tape and the arc described by the buckle. This will vary between designs of PFD. A recommendation of a specific webbing length would therefore be inadvisable. However understanding the relationship to achieve better performance would appear critical.

Activation of the release is currently recommended by pulling on the webbing or toggle (Ferrero, 2008). Anecdotal concerns regarding the security of the toggle release have been raised (Onions and Collins 2013). However it is clear from the direct observations that the toggle activated release pulls the buckle/tri-glide away from the PFD, contributing to the physical separation of the components. Webbing activated releases, do not encourage separation of the buckle/tri-glide components and are more prone to problems following activation. These difficulties are compounded should an inexperienced user continue to hold onto the webbing.

The release of the QRH is dependent upon a load (induced by water flow) at the dorsal point of attachment of the PFD wearer. A tensioning system, integral to the harness ensures a load is applied between part 1 and 2 at the buckle/tri-glide mechanism. This tensioning aids physical separation, irrespective of the load at the dorsal point. The release is improved in terms of speed and quality. This adaptation reduces the critically of the tape length distal to the buckle/ tri-glide.

Following separation of buckle/tri-glide and webbing components, the webbing is drawn through a series of loops and fabric tubes that are integral to the design of the PFD. We speculate that in some designs of PFDs these loops and tubes also redirect the webbing and the friction generated clearly places demand on the load at the dorsal point of attachment. Clearly the dorsal locating points are crucial to ensure correct body positioning in the water, however the benefit of additional loops and tubes becomes questionable. Clear benefits can be attributed to threading the PFD in such a manner as to reduce friction by excluding unnecessary redirection. This however may lead to the webbing being higher under the arms of the user depending upon the design of the PFD and the size of the user.

Multiple users of single PFDs in training and rescue situations place sizing and fitting demands on the PFD and QRH. The adaptation made to the harness in this research, enabled the adjustment of tape length at the buckle and has offered a parsimonious solution to the multi user, tape length problem. Namely the integration of an adjustable load bearing buckle connecting part 1 and 2 will enable sizing of the harness on issue prior to use.

Conclusion

The most effective releases, in this series of tests, have been achieved by adjusting the tape to ensure physical separation of webbing and buckle/tri-glide mechanism. A simple test while fitting and donning the PFD to activate the QRH release and ensure part 1 and 2 separate would indicate correct sizing and fitting of the harness. Design and manufacture of the PFD will vary, as will the attachment point of the QRH to the PFD. As a result recommendation cannot be made regarding a specific length of webbing. The relationship, however, between the attachment point (PFD to QRH) and tape length being crucial to release. Adjustment of the tape in part 2 and or alteration of the attachment point of part 1 in the relationship $Y+2a<C/4$ to the PFD will contribute to the effectiveness of the release illustrated in Fig 4.

Activation of the release by pulling the toggle away from the body separates the buckle/tri-glide mechanism from the PFD and facilitates the desire separation of webbing and mechanism toggle activation being preferable to webbing activated release that delays and complicates the release. Following release with the toggle, the rescuer should then adopt the ‘star shape’ to expose maximum body surface area to the flow in order to maximise load on the system this pulls the tape from around the PFD. The loops on the rear of the PFD should be used to ensure the attachment point facilitates the correct body position in the water but other loops or tubes need not be used. The tape separates from the PFD following release and reduces friction between PFD and tape.

Adjusting the release mechanism and tape length would enable a consistent use of the load bearing back bar (Tri-Glide) at the release mechanism. In this respect removing the judgement call required when threading the QRH prior to entering the water.

For multi users this trimming of the tape will be impractical and we suggest the desired separation can be achieved by adjusting the webbing via an adjustable load bearing buckle that is positioned between part one and two of the QRH. While we used a doubled back three bar buckle to connect part 1 and 2 other buckle configuration could clearly be used.

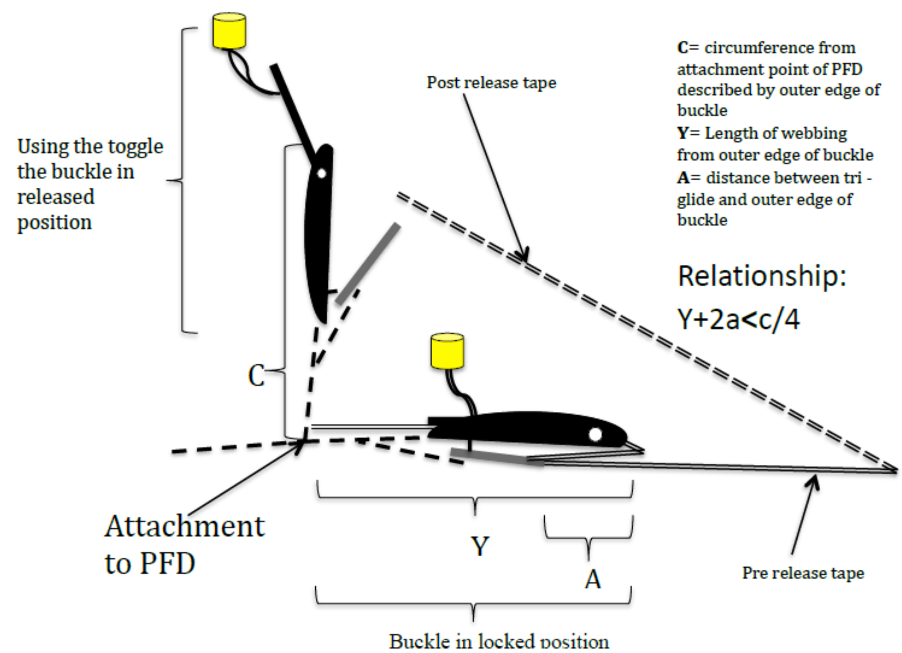

Figure 4: Illustrating the relationship between attachment to PFD and tape length in locked and unlocked positions

Under low flow conditions the pre tension in the harness system, (as outlined) provides an added tension during release and ensures separation of the release mechanism and tape. This would be advantageous in QRH that may be used in both low and high flow conditions. In addition to the conclusions above a reduction in the threading loops and tubes *and* the *Velcro*™ dorsal locating patches should be removed from PFD's, as this appears to be an unnecessary additional force associated with the release of the QRH.

We speculate that further improvements could be achieved by utilising wide radius attachment at the dorsal point, such as the wide end of an HMS type karabiner or large fixed ring. However investigation into the judgements and decision-making that is associated with QRH and swift water rescue may be more valuable in the design of effective rescue technician education programs use is still required and will be subject of our next paper. Based on this evidence we make the following recommendations for training and use of QRH.

- The toggle is used as the primary method to activate the release.
- Following release the rescuer assumes a 'star shape' to maximise load in the system
- QRH is adjusted to ensure that when release a physical separation of part 1 and 2 occur.
- QRH are threaded onto PFDs in such as way as to minimise friction between Tape and PFD following release.

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