RESEARCH ARTICLE

# Wearing a crotch strap on a correctly fitted lifejacket improves lifejacket performance

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**Abstract**

Wearing a lifejacket when immersed in water should support the wearer, maintaining their airway clear of the water. It is proposed that a retention system would improve airway protection by improving retention of the lifejacket around the torso. Study one (n=10) quantified the performance of lifejackets immediately following a step into water from height when a lifejacket was worn with a crotch strap (two different tightness) and without a crotch strap. Airway freeboard was improved when wearing a crotch strap ($P<0.05$) compared no crotch strap. Study two used a manikin to examine the performance of lifejackets with and without a crotch strap during three-hour exposures to waves. During exposure to waves, the time taken to aspirate the lethal dose of seawater for drowning was doubled when wearing a crotch strap compared to the no crotch strap conditions ($P<0.001$). Therefore wearing a crotch strap (functioning retention system) on a correctly fitted lifejacket improves airway protection following accidental immersion and prolonged wave exposure.

Keywords: lifejacket retention, airway protection, drowning

**Practitioner Summary**

Following a step from height into water, wearing a crotch strap on a correctly fitted lifejacket improved lifejacket performance. Wearing a lifejacket with the crotch strap fitted minimised the reduction in lifejacket performance, compared to the no crotch strap condition, when exposed to waves for three hours.

## Introduction

To perform optimally, lifejackets must be retained around the body of the wearer, self-right and maximise the airway freeboard of the wearer. However, anecdotal evidence suggests that this is not always the case. Specific reference to lifejackets ‘riding up’ over the torso

and head of casualties has been noted in fatal accident reports (Marine Accident Investigation Branch [MAIB] Report No. 7/2007 and Brandstorm *et al* [2006]).

Despite anecdotal evidence of the benefit of lifejacket retention systems, there is a paucity of research investigating retention of a lifejacket. Higenbottam and Redman (1990) found that airway clearance (freeboard) was increased by an average of 14 mm when volunteers entered water from height when wearing a lifejacket with thigh straps compared to wearing the lifejacket without thigh straps. Thus suggesting that thigh straps improve lifejacket performance by increasing the clearance of the airway from the water. Stepping into water from height is one means by which an upward vertical force can be applied to a lifejacket and which may cause a lifejacket to ride up the torso of the body, reducing performance; prolonged exposure to waves also provides repeated vertical forces that could do the same.

Lifejacket performance can be assessed in terms of the distance of the airway from the water line ("airway freeboard"), the angle at which the torso floats in the water ("flotation angle"), the distance the jacket can be moved up the torso ("vertical displacement"), the amount the waist strap and crotch strap slips ("waist strap and crotch strap slippage"). These performance measurements provide information on the airway protection provided by maintain the airway clear of the water line (airway freeboard and flotation angle), the ability of the lifejacket to self-right the wearer and prevent vertical bobbing when exposed to waves (flotation angle) and the fit of the lifejacket (vertical displacement, waist strap and crotch strap slippage). Although described separately, these variables are all linked and help to maximise airway protection.

Additional measurements can be made using a manikin which has a head that measures the volume of water taken into the airway (Tipton 2001). As the manikin does not breathe, water enters the airway passively when it is submerged ("passive aspiration"). The time taken to passively aspirate the lethal dose of water can be measured. Irreversible drowning occurs when 22 $mL.kg^{-1}$ (1540 mL for a 70 kg man) of seawater or 44 $mL.kg^{-1}$ (3080 mL for a 70 kg man) of fresh water is aspirated (Modell & Moya, 1966). Of note, this time does not equate to survival time; it is an estimation of the time it would take an unconscious casualty to aspirate 1540 mL or 3080 mL, respectively. It provides no prediction of the time it would

take an individual to become incapacitated and their airway submerged. Thus, the drowning manikin provides an indication of the level of airway protection provided by a lifejacket, it does not provide a prediction of survival time.

Advice from maritime safety agencies, such as the Royal National Lifeboat Institution (RNLI) and Maritime Coastguard Agency (MCA), has been that retention systems should be worn to improve lifejacket performance. Many manufacturers now supply lifejacket retention systems (crotch straps or thigh straps) either as standard or as an accessory. However, despite the advice and provision of retention systems there has been no research undertaken to support this advice. Manufacturers are required (ISO 12402) to prevent lifejackets from being dislodged or slipping off during testing (i.e. retention must be considered in the design, but a retention system is not required). The standards try not to over-specify lifejacket design; this allows manufacturers to decide how to achieve retention.

As there is limited empirical evidence of lifejacket performance when lifejacket retention systems are worn, the aim of this study was to quantify the impact that crotch straps have on lifejacket performance when a single vertical force and repeated vertical forces act upon the body and lifejacket. Consequently, it was hypothesised that:

(a) Wearing a lifejacket retention system (a crotch strap in this instance) would improve lifejacket performance when stepping into water from height (1 m and 4 m)
(b) Wearing a tightly fitted crotch strap would improve lifejacket performance more than wearing a looser but functioning crotch strap fitted for comfort or no crotch strap when stepping into water from height (1 m and 4 m)
(c) Wearing a lifejacket with a crotch strap would improve lifejacket performance compared to wearing a lifejacket without a crotch strap when exposed to waves for up to three hours

**Methods (Part 1. Stepping into water from height)**

## Participants

Ten participants (five males and five females) of differing height and body mass volunteered for the study and provided written informed consent. The mean and standard deviation (SD)

physical characteristics of the participants: Age 30 (5) years, Height 1.70 (0.11) m tall, Mass 77.32 (16) kg, Body mass index 26.5(4.8) $kg.m^{-2}$, Sitting height 1.31 (0.04) m, Chest girth 0.95 (0.11) m. Prior to testing, participants were familiarised with all the test and safety procedures, they performed a 25 m (one length) swim test and were taught how to correctly don a lifejacket and enter the water safely when stepping. They were also asked, if the lifejacket inflated, to relax and act as a dead weight.

## Standard Clothing and Lifejackets

Prior to each test, participants donned a set of dry standard clothing, this included a swimming costume, short sleeve collared t-shirt, fleece pullover and cotton chino trousers. Shoes were not worn during the study as some types of footwear provide additional flotation (Barwood *et al,* 2011) and may alter flotation angle.

Three lifejackets were selected as they were compliant with ISO 12402 Part 3, in the 150 N of buoyancy class, included a single crotch straps fitted by the manufacturers', 33g Carbon dioxide cylinders. One lifejacket was chosen from the high, middle and low price range of the 150 N buoyancy class. All lifejackets provided 150 N of buoyancy when fully inflated. Further logistical influences also played a part in the selection of the lifejackets tested; these included ease of repacking, availability of the quantity of lifejackets required and availability of auto inflation cartridges. Participants were fitted for the 'tight' and 'comfort' fit crotch straps conditions in each lifejacket. This was quantified by measuring the excess webbing passed through the buckle so that the crotch strap tightness would be consistent within each participant for each condition. The two crotch strap fit descriptions were: "Tightly fitted", defined as the upper limit of comfort, and "Comfort fit" described as looser than the tight fit for comfort, but still functional.

## Test Procedures

All participants performed 30 tests, 10 in each lifejacket. In each lifejacket the following conditions were tested:

Conditions performed from 1 m: Conditions performed from 4 m:

No crotch strap

| | |
|---|---|
| Crotch strap fitted for comfort | Crotch strap fitted for comfort |
| Crotch strap fitted tightly | Crotch strap fitted tightly |

Each of the five conditions was repeated so that an assessment of reliability could be made. The research steering group considered the step from 4 m without a crotch strap to be too hazardous to perform. Therefore, this condition was not performed.

Once dressed in the standard clothing, lifejacket donned correctly and crotch strap adjusted according to the condition, measurements of lifejacket vertical displacement were recorded and Chinagraph pencil marks made and measured on the waist strap and crotch strap. Volunteers then stepped into the water from either 1 m or 4 m. After entering from height, the water was allowed to settle before airway freeboard and flotation angle were measured, the volunteer was assisted to exit the pool and vertical displacement, waist strap and crotch strap slip on the lifejackets were also measured.

## Measurements

### *Airway Freeboard (cm)*

Airway freeboard measurements were made after the participant had stepped into the water, once the water had settled, and is the distance from the surface of the water to the lowest part of the airway of the participant. Data from tests which did not self-right were not included in the mean data, but are shown in Figures 1 and 2.

### *Flotation Angle (°)*

Flotation angle was measured in relation to the vertical (0°), using a line from the shoulder to the hip. The angle was measured from the side of the body using a floating protractor.

### *Vertical Displacement (cm)*

The vertical displacement of the lifejackets was recorded before and after the step into the water by lifting the lifejacket up the torso using a standard upward force of 15 kg (147 N). A Chinagraph mark was placed on the back of each lifejacket; the vertical displacement was recorded as the distance the mark moved when no force was applied and the 15 kg (147 N) was applied to the jacket. This amount of force was required to take up the slack in the lifejacket straps, without excessive compression of soft tissue and clothing.

### *Crotch strap slip(cm)*

The length of free strap beyond the crotch strap buckle was measured using a tape measure. The length was re-measured after the immersion and the difference between the two measurements was calculated as the amount the crotch strap had slipped.

### *Waist strap slip (cm)*

The amount the waist strap slipped was measured by marking the strap and measuring the position of the mark in relation to the buckle prior to the immersion. The position of the mark in relation to the buckle was then re-measured upon exiting the pool after the immersion. The difference between the two measurements was calculated as the amount the waist strap had slipped.

### *Data analyses*

Data are presented as means and standard deviations (SD); data points were not included for airway freeboard and flotation angle where the lifejacket did not self-right the volunteer. Where normality of distribution was found, repeated measures Analysis of Variance (ANOVA) with *post-hoc* pair-wise comparisons and Bonferroni adjustment was used to establish if there were differences between crotch strap conditions (no crotch strap, comfort fit and loose fit crotch strap). Where the data were not normally distributed a non-parametric Friedman's ANOVA was used with *post-hoc* Wilcoxon Signed Rank tests. Statistical significance was accepted at an alpha level of $p<0.05$ for one-tailed tests.

Each condition was performed twice by each volunteer; reliability of the data has been reported by coefficients of variation for each of the crotch strap conditions when stepping in

to water from a height 1m and 4m. Coefficients of variation were calculated for airway freeboard, flotation angle and vertical displacement.

**Results**

Seven of the ten volunteers were consistently self-righted by the lifejackets. The analyses have been completed on these seven volunteers for freeboard and flotation angle. The data of all ten volunteers have been used for other variables, as self-righting performance had no effect on these data.

Airway freeboard measured immediately following a step from 1m was greater in the comfort fit and tight fit crotch strap compared to the no crotch strap condition *(P*<0.05, Table 1). Moreover, when stepping from 1m, the airway freeboard did not differ between the comfort fit and tight fit crotch strap conditions. In contrast, when stepping from 4m, wearing a tightly fitted crotch strap increased airway freeboard in comparison to the comfort fit (*P*<0.05, Table 2).

Compared to the no crotch strap condition the comfort fit and tight fit crotch strap conditions improved airway freeboard *(P*<0.05, Table 1). Moreover, when the raw data were compared to arbitrary freeboards of 8, 10 and 12 cm, approximately 30 % more tests in the crotch strap conditions exceeded these freeboards compared to the no crotch strap condition (Figure 1). On average, when stepping from 4m, wearing a tightly fitted crotch strap increased average airway freeboard by 9 % compared to the comfort fit (*P*<0.05, Figure 2). Furthermore, when the raw data were compared to arbitrary freeboard values of 8, 10 and 12 cm, 7 to 17 % more tests in the tight fit crotch strap condition exceeded these arbitrary freeboards than in the loose fit crotch strap condition (Figure 2).

Associated with the improved freeboard there was a mean increase in flotation angle when stepping from 1m, from 38 (12)° with no crotch strap to 42 (11)° and 45 (9)° with a crotch strap fitted for comfort and a tightly fitted crotch strap in those volunteers whose lifejackets self-righted them. The flotation angle was significantly greater when a crotch strap was

worn, compared to the no crotch strap condition ($P$<0.05, Table 1). However, when stepping from a height of 4m above the water there were no differences in flotation angle between the comfort fit and tight fit crotch strap conditions (Table 2).

Immediately following the 1 m step, vertical displacement of the lifejacket was greater in the no crotch strap condition compared to the comfort fit crotch strap condition ($P$=0.002) and greater in the no crotch strap condition compared to the tight fit crotch strap condition ($P$<0.001, Table 1). In addition, immediately following the 4 m step from height, vertical displacement of the lifejacket was greater in the comfort fit crotch strap condition compared to the tight fit crotch strap condition ($P$=0.049, Table 2).

Waist strap and crotch strap slippage were similar when stepping from height. Consequently, no between crotch strap condition differences were found in the amount of waist strap or crotch strap slippage when stepping into water from 1 m or 4 m (Tables 1 and 2).

Co-efficients of variation were calculated for each crotch strap condition for 1m and 4m steps from height for airway freeboard, flotation angle and vertical displacement. Co-efficients of variation for airway freeboard were between 11 % and 60 %, for flotation angle 31 % and 48 % and for vertical displacement were between 21 % and 124 %.

**Methods (Part 2. Prolonged exposure to waves)**

## Manikin

The experiment was carried out using a Robert Gordon Anthropometric Marine Manikin (RAMM 2), designed to have a similar density to humans and therefore float like an unconscious human (Avery & Light, 1988). The head was modified to enclose a unit which records the amount of water taken into to the airway of the manikin ('passive' aspiration) and transmits the readings to a receiver on the poolside (Tipton *et al,* 2001).

## Standard Clothing and lifejackets

The manikin was also dressed in the standard clothing ensemble described in part one. In addition, all the lifejacket and crotch strap conditions were tested when the manikin wore

the standard clothing and a foul weather ensemble, which consisted of standard RNLI crew foul wear trousers and jacket. The hood of the jacket was stored within the neck of the jacket.

The three 150 N lifejackets used in study one were also used in the present study, in addition three different manufacturers lifejackets from the 275 N buoyancy class were also tested in this second study. All the jackets required full inflation none contained any inherent buoyancy. One of the jackets was supplied with a double crotch strap; the others were supplied with a single crotch. For conditions where a second crotch was required an additional webbing crotch strap was looped on the lifejacket.

Air trapped within the layers of clothing and in shoes would provide additional flotation, possibly influencing flotation angle and freeboard (Barwood *et al*, 2011). In order to ensure that any change in lifejacket performance was caused by the crotch strap condition and not the volume of trapped air in the clothing, on entry to the water, excess trapped air was removed from the clothing by the hydrostatic squeeze of the water and by patting down the arms, legs and torso of the clothed manikin.

## Test procedures

Three 150 N lifejackets (those used in study one) and three 275 N lifejackets were tested in the standard clothing conditions, then with standard clothing and a foul weather ensemble, using each of the two crotch strap designs (single and double crotch straps) and a no crotch strap condition. The crotch straps were tightened according to the fit recommended from part one (a tightly fitted crotch strap) for a similarly sized human. The crotch straps were tightened to the same extent in the standard clothing ensemble and the foul weather ensemble. In total 36 tests were performed, 12 in each crotch strap condition.

Once dressed, the vertical displacement of the lifejacket on the torso was measured. The waist strap and crotch strap were marked when the lifejacket was uninflated and then again when inflated whilst the manikin was on the poolside. The manikin was then lowered (using helicopter strops attached to a winch) into calm water. Airway freeboard and flotation angle were measured at the start and end of a 30 minute calm water exposure. The manikin was

then brought to the side of the pool lifted clear of the water using the strops and the winch, and the vertical displacement and waist belt and crotch strap slip were measured. The manikin was then placed back into the water, tethered in the centre of the pool and exposed to three hours of waves. The manikin testing was performed at the RNLI's Sea Survival Centre (waves were produced using the 'Parallel' wave pattern of the wave machine). The average (SD) wave height 0.45 (0.2) m and frequency 1.8 (0.5) s were calculated, (maximum wave height was 1.2 m and minimum wave height was 0.2 m). The wave pattern was of a reproducible pattern, which repeated itself over a 10 minute cycle; this ensured that the wave energy applied during each test was similar. During the wave exposure, the volume of water passively aspirated was recorded each minute. Once the three-hour wave exposure was complete and the waves calmed, flotation angle and freeboard were measured and the manikin was removed from the water for the re-assessment of vertical displacement, waist strap and crotch strap slip.

## Measurements

Measurements of airway freeboard, flotation angle, crotch strap and waist strap slip were made as described in part one and recorded before and after each calm water and wave exposure. Vertical displacement of the lifejacket was measured using the same equipment and techniques as described earlier, but performed horizontally, attaching a strop round the back of the manikin and winching the manikin approximately 10 cm from the ground. In addition, passive aspiration of water was measured using the drowning manikin head, first used by Tipton *et al* (2001). During the wave exposure, the volume of water aspirated was recorded each minute until the manikin had passively aspirated the "lethal" dose for drowning in salt water (22 $ml.kg^{-1}$, 1.54 L for a 70 kg person).

## Data analyses

Although a number of different conditions were tested, repeated measures ANOVA with pair-wise *post hoc* analysis or non- parametric equivalents were used to test for differences between crotch strap conditions (no crotch strap, a single crotch strap and a double crotch strap).

The time taken to accumulate the lethal dose of water to drown was correlated (using a spearman's rank order correlation coefficient) with airway freeboard, flotation angle and vertical displacement measured before three hours of wave exposure.

For this second study, Pearson product moment correlations were also calculated (separately for the 150 N and 275 N lifejackets) between passive aspiration and other lifejacket performance indicators to establish which was the best measure of airway protection (Table 4).

**Results**

No differences in any variables were found during the calm water exposures.

Wearing the single crotch strap and double crotch strap doubled the time taken to aspirate 1.54 L of water compared to the no crotch strap condition (both $P<0.001$, Table 3). No differences in the time taken to aspirate 1.54 L of water were found between the single and double crotch strap conditions.

The change in airway freeboard following three hours of exposure to waves was greater in the no crotch strap condition compared to both the single crotch strap condition ($P=0.021$) and double crotch strap condition ($P=0.025$, Table 3).

A greater reduction in flotation angle was found in the no crotch strap condition compared to the single crotch strap ($P=0.018$) or double crotch strap conditions ($P=0.007$, Table 3).

There were no differences in vertical displacement between crotch strap conditions before the three-hour wave exposure. In contrast, following the three-hour wave exposure, the change in lifejacket vertical displacement was significantly greater in the no crotch strap conditions compared to both the single crotch strap conditions ($P=0.021$) and the double crotch strap conditions ($P=0.015$, Table 3).

Following a three-hour exposure to waves a small (1mm), but statistically significant reduction in waist strap slip was found in the double crotch strap conditions compared to

the no crotch strap conditions ($P$=0.024) and the double crotch strap conditions compared to the single crotch strap conditions ($P$=0.008, Table 3).

The time taken to accumulate the lethal dose of water to drown (1.54 L) was positively correlated with airway freeboard and flotation angle, but negatively correlated with vertical displacement (Table 4). Therefore in both the 150 and 275 N lifejackets, the greater the airway freeboard and flotation angle observed the longer it took to accumulate the lethal dose of water to drown. Conversely, the larger the vertical displacement, the shorter the duration required to accumulate the lethal dose of water to drown.

**Discussion**

Much unsubstantiated anecdotal opinion abounds on the subject of crotch straps, some say they are advantageous, others that they represent a snagging hazard. The common factor that unites both of the disparate views is the almost complete lack of underpinning, carefully controlled scientific evidence to support either of them. The present research has, for the first time, attempted to address this shortcoming and quantify the effect of wearing a crotch strap with a correctly fitted lifejacket and shown that a crotch strap improves lifejacket performance during the application of two types of vertical force (entry to water from height and prolonged exposure to waves). The snagging hazard associated with crotch straps remains to be investigated (Tipton & Gillis, 2012).

When measured immediately following a step from height into water, wearing a crotch strap improved airway freeboard, provided an improved flotation angle and reduced vertical displacement. Despite the variability in these data, there is still an important message that is apparent. These data provide evidence of improved lifejacket performance when a crotch strap is worn, thus hypothesis (a) can be accepted. Furthermore, a tightly fitting crotch strap improved lifejacket performance to a greater extent than wearing a lifejacket with a crotch strap fitted for comfort, therefore hypothesis (b) can be accepted.

When assessed against arbitrary freeboard values of 8, 10 and 12 cm, 30 % more tests conducted from 1m steps from height achieved these freeboard values when the crotch

strap was tightly fitted or fitted for comfort compared to the no crotch strap conditions. The same criteria were applied to the 4m step tests, and between 7 % and 17 % more tests met these freeboard values when a crotch strap was tightly fitted compared to a crotch strap fitted for comfort. These findings provide further evidence of the improvement in airway freeboard immediately following a step from height into water. The finding, implicit in these data, that lifejackets which had passed the ISO standard for airway freeboard appeared to not achieve the arbitrary criteria in the present test, can be explained by the fact that the current tests did not correspond to the ISO test protocol. This was to ensure that humans were tested in realistic clothing assemblies with lifejackets and crotch straps attached. When testing to the standard ISO 12402, swimwear is used (due to problems of specifying clothing). In real world situations, lifejackets tend to be worn over clothing. It is possible that a closer fit is achieved when wearing a lifejacket over swimwear than clothing. Although clothing can be compressed, it will move, consequently allowing the lifejacket to move. Therefore, wearing clothing with lifejackets may alter the performance of the lifejacket and thus alter the performance in relation to the ISO standard.

Study two is the first to specifically investigate the use of a crotch strap on lifejacket performance during prolonged exposure to wave conditions using a RAMM to simulate an unconscious casualty. The data suggest that wearing a correctly fitted lifejacket with a crotch strap during exposure to waves reduces the decrement in lifejacket performance compared to wearing a lifejacket without a crotch strap. Therefore, hypothesis (c) can be accepted. A crotch strap minimised the reduction in airway freeboard, maintained flotation angle to a greater extent, prevented large increases in vertical displacement and extended the time taken to aspirate the lethal dose of water. The maintenance of lifejacket performance when wearing a correctly fitted lifejacket and a crotch strap are indicative of improved airway protection.

A comparison of the effect that a single and double crotch strap have on lifejacket performance found a small difference in the amount of waist strap slippage between the single and double crotch strap conditions. However, no additional improvement in lifejacket performance was observed when wearing a lifejacket with a double crotch strap compared to a single crotch strap. As the crotch straps in the double crotch strap conditions were

tightened to the same extent and were of similar tightness to those in the single crotch strap conditions, it is unlikely that there would be any improvement in performance. The choice of single or double crotch straps may be preferred by the user for reasons of comfort: such a preference was not determined in the present study.

A drowning manikin head as a measure of airway protection will not be available to all lifejacket test houses, therefore establishing the association between this measure and more easily measured performance variables will ensure that airway protection during prolonged exposures can be assessed indirectly. For 150 N lifejackets similar strength correlations between the average time taken to passively aspirate 1.54 L of water and airway freeboard, flotation angle and vertical displacement indicate that for the this class of lifejacket there is no one single variable which should be used as a surrogate measure of airway protection. In contrast for the 275 N lifejackets, the strongest correlation ($r=-0.88$) showed that the smaller the vertical displacement of the lifejacket the greater time taken to aspirate 1.54 L of water, a close second was a positive correlation ($r=0.808$), indicating that a greater freeboard was also associated with longer times to aspirate 1.54 L of water. These analyses suggest that airway freeboard, flotation angle and vertical displacement data should all be considered when assessing the airway protection of 150 N lifejackets, whereas vertical displacement of the lifejacket and airway freeboard were most indicative of airway protection when examining the performance of 275 N lifejackets.

Both experiments (entry to water from height and prolonged wave exposure) indicated that wearing a crotch strap improves lifejacket performance. However, the magnitude of the improved performance when wearing a crotch strap is much greater during prolonged wave exposure than stepping into water from height. The wave exposure tests involved exerting vertical forces on the body and lifejacket for an extended time (three hours), whereas the step into water from height tests involved a short exposure; a single vertical force acting on the body and lifejacket. Therefore, a test involving repeated exposures to vertical forces may provide the more discriminating test of lifejacket performance than a shorter duration test where a single vertical force is applied.

It is concluded that wearing a correctly fitted lifejacket with a single, tightly fitted, crotch strap improves lifejacket performance and thereby airway protection compared to wearing a lifejacket without a crotch strap when stepping into water from height (a single vertical force), or when exposed to wave conditions for prolonged periods (repeated vertical forces).

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**Legends**

**Figure 1.** Scatter plot of individual airway freeboard when wearing either no crotch strap, a crotch strap fitted for comfort or a tightly fitted crotch strap, following a step from 1 m. Dashed line = 8cm freeboard, dotted line = 10 cm freeboard, and solid line = 12 cm freeboard. The text immediately above each line indicates the number of tests which exceeded the freeboard value for each crotch strap condition. NB. The negative values occurred due to individuals failing to self-right and, as a consequence, their airways remaining below the surface of the water.

**Figure 2.** Scatter plot of individual airway freeboard when wearing a crotch strap fitted for comfort or tightly fitted following a step from 4 m. Dashed line = 8cm freeboard, dotted line = 10 cm freeboard, and solid line = 12 cm freeboard. The text immediately above each line indicates the number of tests which exceeded the freeboard value for each crotch strap condition. NB. The negative values occurred due to individuals failing to self-right and, as a consequence, their airways remaining below the surface of the water.

**Table 1.** Mean (SD) of lifejacket performance variables for all lifejackets immediately following a step from 1 m when the lifejacket was worn without a crotch strap, with a crotch strap fitted for comfort and a tightly fitted crotch strap. * Different from no crotch strap condition, $P<0.05$. $n=10$ unless otherwise indicated.

**Table 2.** Mean (SD) of lifejacket performance variables for all lifejackets immediately following a step from 4 m when the lifejacket was worn without a crotch strap, with a crotch strap fitted for comfort and a tightly fitted crotch strap. * Different between comfort fit and tight fit crotch strap conditions, $P<0.05$. $n=10$ unless otherwise indicated.

**Table 3.** Mean (SD) of lifejacket performance variables following a three-hour wave exposure when the manikin wore a lifejacket without a crotch strap, with a single crotch strap or with a double crotch strap. * Different from no crotch strap condition, $P<0.05$. $n=12$.

**Table 4**. Correlation coefficients for 150 N and 275 N lifejackets. The time to aspirate 1.54 L of water during a three-hour exposure to waves correlated with other lifejacket performance variables. * Different from no crotch strap condition, $P<0.05$.

## Figures

Figure 1.

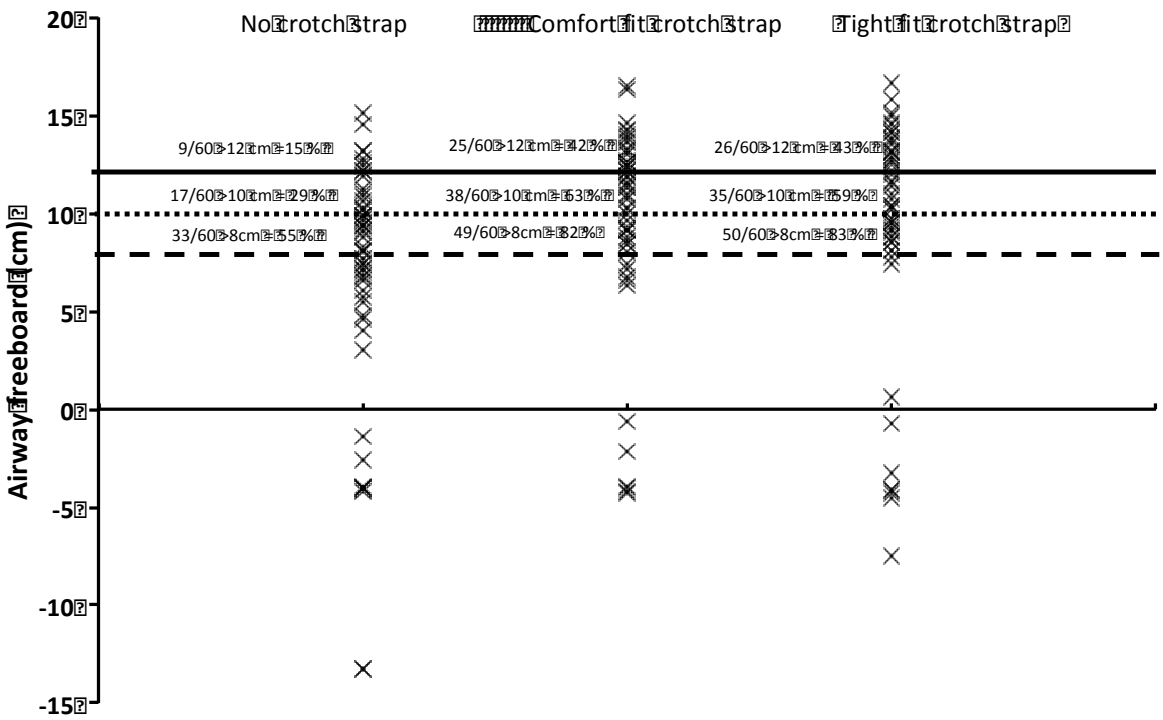
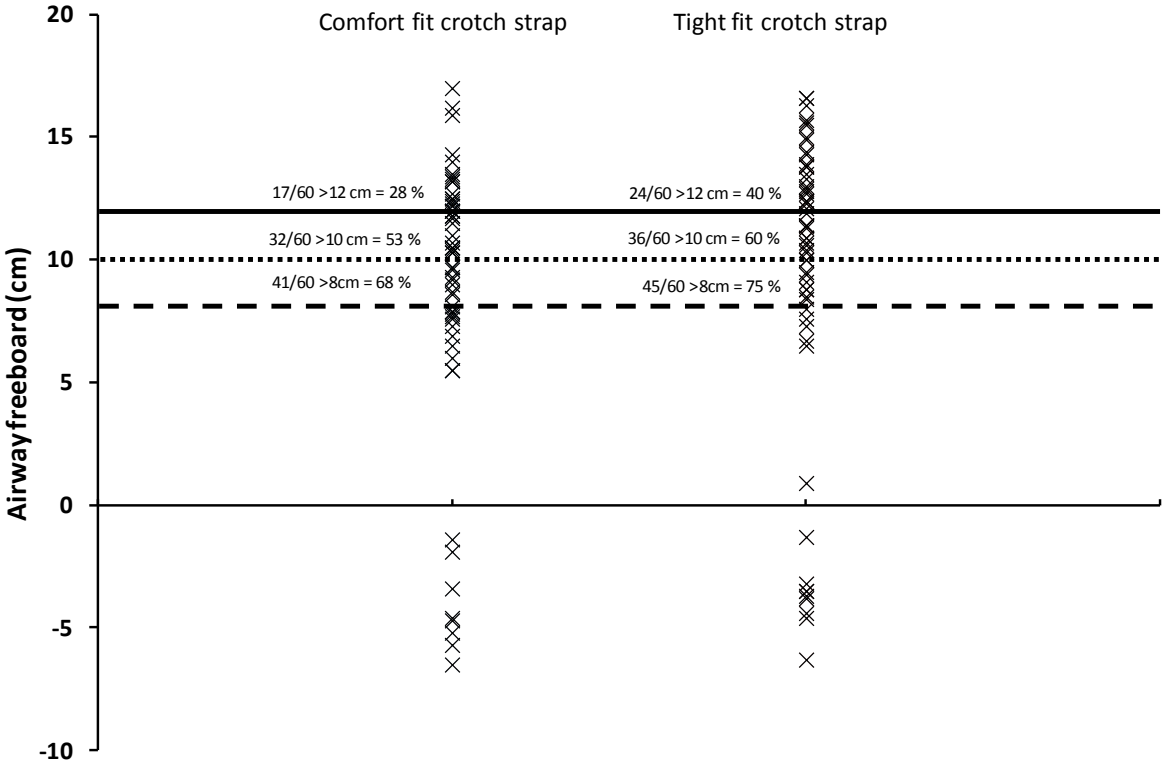


Figure 2.


Comfort fit crotch strap
Tight fit crotch strap
Airway freeboard (cm)
20
15
10
5
0
-5
-10
17/60 >12 cm = 28 %
32/60 >10 cm = 53 %
41/60 >8cm = 68 %
24/60 >12 cm = 40 %
36/60 >10 cm = 60 %
45/60 >8cm = 75 %

**Tables**

**Table 1.**

| | Crotch strap fit | | |
|---|---|---|---|
| | **No crotch strap** | **Comfort fit crotch strap** | **Tight fit crotch strap** |
| **Airway freeboard (cm)[a]** | 8.7(0.3) | 10.8(3.4)* | 11.3(3.2)* |
| **Flotation angle (°)[a]** | 38(12) | 42(12)* | 45(9)* |
| **Vertical displacement (cm)** | 4.1(3.8) | 3.2(3.2)* | 2.9(3.1)* |
| **Waist band slip (cm)** | 0.4(0.2) | 0.4(0.2) | 0.4(0.2) |
| **Crotch strap slip (cm)** | N/A | 0.4(0.2) | 0.3(0.2) |

[a] *n*=7

**Table 2.**

| | Crotch strap fit | |
|---|---|---|
| | **Comfort fit crotch strap** | **Tight fit crotch strap** |
| **Airway freeboard (cm)[a]** | 10.7(2.6)* | 11.7(2.5) |
| **Flotation angle (°)[a]** | 43(12) | 44(10) |
| **Vertical displacement (cm)** | 3.9(4.4)* | 2.9(2.9) |
| **Waist band slip (cm)** | 0.4(0.2) | 0.4(0.2) |
| **Crotch strap slip (cm)** | 0.4(0.3) | 0.3(0.2) |

[a] *n*=7

**Table 3.**

| | Crotch strap fit | | |
|---|---|---|---|
| | **No crotch strap** | **Single crotch strap** | **Double crotch strap** |
| **Time to aspirate 1.54 L of water (min)** | 29(17) | 53(11)* | 57(9)* |
| **Change in Airway freeboard (cm)[a]** | 4.5(2.4) | 3.1(2.1)* | 3.1(1.2)* |
| **Change in Flotation angle (°)[a]** | -5.4(3.4) | -2.0(1.2)* | -1.5(1.8)* |
| **Change in Vertical displacement (cm)** | 3.7(3.6) | 1.0(1.4)* | 0.3(1.1)* |
| **Waist band slip (cm)** | 0.2(0.2) | 0.2(0.1)* | 0.1(0.0)* |
| **Crotch strap slip (cm)** | N/A | 0.1(0.1) | 0.1(0.1) |

**Table 4.**

| | Lifejacket buoyancy | |
|---|---|---|
| | **150 N** | **275 N** |
| **Airway freeboard (cm)[a]** | 0.700* | 0.808* |
| **Flotation angle (°)[a]** | 0.636* | 0.612* |
| **Vertical displacement (cm)** | -0.658* | -0.880* |
| **Waist band slip (cm)** | 0.069 | -0.550* |