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Design of novel buoyant swimming vest using inlay knitting technology

Abstract

The use of children's buoyant swimwear has become more common. However, its bulkiness and hardness restrict the wearer's movement. For better fit, comfort and mobility, a knitted buoyant swimming vest is developed. It is compared with two market samples using subjective evaluation according to the Functional, Expressive, and Aesthetic (FEA) Consumer Needs Model and laboratory tests of objective measurements. The results of a paired-sample t-test show that a tightly fitting buoyant swimming vest should be worn out of water, as the vest becomes a perfect fit in water. Tests on the knitted buoyant swimming vest demonstrate improved functionality and higher buoyancy than that of two market samples conforming to British Standard EN 13138-1:2014. The results of repeated measures ANOVA show an overall significant higher satisfaction level in the knitted buoyant swimming vest than two market samples in terms of fit, comfort and mobility. The results of this study are significant for both the textile industry and the fast-growing sportswear industry.

Keywords

Swimwear, Inlay knitting, Buoyancy, Children, FEA model

1. Introduction

Drowning is the leading cause of death from accidental injury among children.[1-3] Consequently, a large variety of buoyant swimsuits and swimming aids have been developed to increase children's safety during recreational swimming, to preserve warmth and to build confidence in water, especially for beginner swimmers.[4] A swimmer's fear of water may be due to the unbalanced buoyancy of the human body, which may result in sinking and the inhalation of water through the mouth and the nasal passages.[5] Therefore, a beginner's anxiety can be reduced by using buoyant swimwear to maintain their buoyancy. In recent decades, foam blocks have been used as the main medium of buoyant swimwear. They are sewn in the swimwear to provide integral buoyancy, or they are placed securely in the pockets around the waist or chest to provide adjustable buoyancy.[5-11] The buoyant foam used in the swimwear is commonly made from neoprene, expanded polystyrene, polyethylene, ethylene vinyl acetate (EVA) foam and polyurethane.[5, 6, 8-10, 12] Sufficient buoyancy is provided by the swimwear high upon the body of the wearer to preclude the immersion of the wearer's breathing passages when in water.[7] Therefore, various designs of buoyant swimwear incorporated foam blocks wrapped around the chest of the wearer.[5, 8, 10] Buoyant foam panels with crease lines to facilitate the wearer's movement have been incorporated in the swimwear' front and back upper body panels.[13] However, current buoyant swimwear has differing levels of fit, comfort and mobility. Swimwear with foam blocks have been criticised as extremely bulky due to the lack of distribution in their buoyancy.[7] The wearer's movement is obstructed while wearing these swimwear, and the displacement of the swimwear when in use presents a problem.[5] An increase in the buoyancy of the swimwear inversely affects horizontal swim distance.[14] Therefore, adjustable buoyancy is needed in order for the wearer to be able to reduce the buoyancy of the swimwear as their swimming skills develop.[4]

To reduce the bulkiness of conventional buoyant swimwear, research and experiments were carried out as a means of exploring the benefits of integrating knitting technology into the development of buoyant material.[15, 16] The high extension and recovery properties of knitted fabrics provide incentive to incorporate them into sportswear, as they can stretch by 15%–20% in width without significant yarn extension.[17] Knitted fabrics' stretchiness allows a knitted garment to fit to the wearer's body, which is important for swimwear. However, it was predicted that fabrics consisting solely of knitting yarn would be insufficiently buoyant. Additional materials must be incorporated into knitted fabric to improve its buoyancy. The challenge of incorporating buoyant materials can be overcome by using inlaid knitting, which securely incorporates materials that cannot be made into yarn into the fabric.[18] The principle of the inlay knitting technology is that the yarn carrier supplies knitting yarn prior to the normal timing, the yarn is obstructed from being hooked on to the knitting needles, and material is incorporated into the knit.[19] Thus, the buoyant material can be inlaid into the knitted fabric without forming any loops. This fabric can also be knitted into particular shapes to decrease the number of seams, production time and fabric waste, as compared to cut and sewn products. Inlay knitting has been widely used in structural design, as well as in industrial applications and in the pressure control of compression textiles for therapeutic purposes.[20-22] An inlay structure was also incorporated into the design of the knitwear.[23, 24]

Polypropylene is a buoyant material, due to its low density and the air trapped between its fibres.[25] A buoyant polypropylene fabric was developed for the removal of organic contaminants from water.[26] By following the inlay knitted structure, our research team found that the knitted buoyant fabric inlaid with foam rods has a higher buoyancy than that with buoyant tubes.[16] Also, the net buoyant force of the fabric increases when the inner diameter and linear density of the inlaid tube increases and the outer diameter decreases.[15] When considering aesthetics, UV-curable inkjet printing is an optimal design option for knitted buoyant fabric due to its high-resolution prints compared to water marbling and hand-drawing with acrylic paints.[27] Fabric printed in a color with the greatest lightness and the fewest overprints had the lowest fabric weight and thickness, along with better bending recovery and resilience properties.[28]

The aim of this study was to demonstrate the improved fit, comfort and mobility of buoyant swimming vests by using inlay knitting technology with buoyant foam rods as a substitute for board foam sheets as the buoyant medium in the swimming vest. Changes in the tightness of the buoyant vest out of water and in water were analysed to provide a better understanding of fit. A design process model for the development of buoyant swimwear was first proposed (Figure 1). The first stage was to identify the problems of conventional buoyant swimming vests, followed by analysis of the problem and exploration of possible solutions. The development of the knitted swimming vest was outlined in the second stage. In the final stage, the vest was evaluated by comparison with two market samples on objective and subjective measurements.

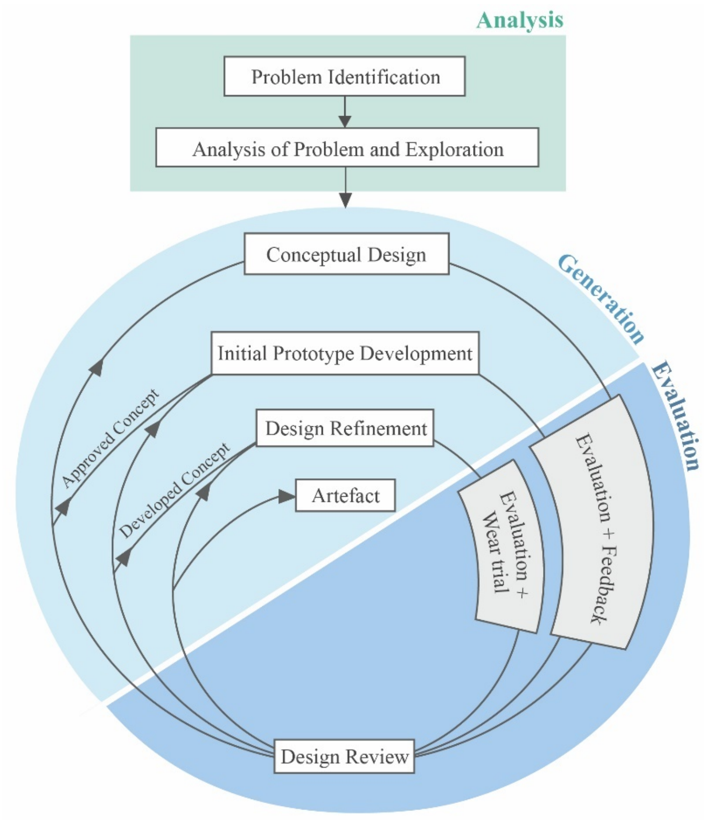


Figure 1. Theoretical design process model for the development of a buoyant swimming vests for children

2. Exploration of knitted buoyant swimming vests

2.1 Problem identification and analysis

By studying numerous patents for buoyant swimwear, [5, 7-11, 29] improvements in conventional buoyant swimwear were analysed and categorised.

2.2 Exploration

Possible solutions were proposed accordingly for prototype development (Table 1). Inlay knitting technology can improve the shape retention properties of knitted fabric, as inlaid knitted fabric can bend to the desired curvature without springing back, providing the vest with a better fit to the body. The buoyancy of the swimsuit can be adjusted by removing the buoyant layers. This adjustable function can serve to reduce the obstruction to horizontal swimming upon development of the wearer's swimming skills.[4, 14] Two market samples were selected for comparison with the knitted buoyant vest in this study (Figure 2). Market sample A (*Splash About*, United Kingdom) is an item of swimwear with integrated buoyancy. It has a printed neoprene shell and four layers of laminated expandable polyethylene (EPE) foam board sewn inside the front and back. Market sample B (*Zoggs*, Australia) is an item of swimwear with adjustable buoyancy. It is composed of a neoprene shell with eight removable EPE foam blocks situated in pockets around the waist. Both selected samples included EPE foam situated inside a shell, as this is one of the most typical design features of buoyant swimwear on the market. A design with foam board surrounding the whole body and a design with foam rods situated at the waist were selected to compare the differences in fit, comfort and mobility satisfaction between various distributions and shapes of foam.

Table 1. Exploration of knitted buoyant swimming vests

Category	Areas of improvement in patented buoyant swimming vests	Design features of knitted buoyant swimming vests
Fit	1 The buoyant swimsuit is displaced away from the body due to buoyancy.[5]	1 The shape retention of knitted buoyant fabric may provide a better fit to the wearer's body.
Bulkiness	2 The bulkiness and inflexibility of foam-based buoyant clothing forces the wearer to swim unnaturally or uncomfortably.[6]	2 Flexible expandable polyethylene (EPE) foam rods can be inlaid into knitted fabric to reduce the bulkiness and inflexibility of foam.
Buoyancy	3 Foam blocks located around the chest provide uneven distribution of buoyancy.[7]	3 Buoyant materials can be distributed evenly around the upper body.
	4 The high buoyancy of integrated buoyant swimwear may inversely affect horizontal swim distance.[14]	4 Adjustable buoyancy can be achieved by removing buoyant layers inside the vest.
Donning and doffing	5 It is inconvenient to remove the entire suit in the event of restroom use or a diaper change.[11]	5 A vest design may be developed instead of a one-piece swimsuit to facilitate the removal of buoyant swimwear.

(a)

(b)

Figure 2. (a) Market sample A (*Splash about*, United Kingdom) and (b) Market sample B (*Zoggs*, Australia)

3. Materials and methods

3.1 Prototype development and design refinement

3.1.1 Development of knitted buoyant fabric

The inlaid knitted buoyant fabric in this study was knitted with 1 × 1 rib structure using one end of the knitting yarn 250D hollow polypropylene and one end of the inlaid EPE foam rods, with a diameter of 6.36 mm. The buoyant fabrics were knitted on a 7 gauge V-bed hand-knitting machine (Wealmart, Hong Kong, China), and the foam rod was inlaid manually during knitting. A space is created between the loops situated on the front and back needle beds in 1 × 1 rib structure so that the foam rod can be laid-in smoothly. The fabric was knitted to match the garment shape to reduce fabric wastage. The structural details of the inlaid fabric are presented in Figure 3, in which the ⊠⧇ symbols represent 1 × 1 rib structure. The crease lines for each panel and a reduction in the garment's outer length was found to facilitate the movement of wearers.[30] In the region with the crease line, a single jersey on the back needle bed was made which allowed the inlaid foam rods to be seen on the front side of the fabric (Figure 4). This facilitated the manual cutting of the foam rods with scissors without cutting the knitted loops at the back of the fabric. After knitting, the foam rods in the knitted fabric was cut at the centre back in the back panel and at the middle of the waist panel, as shown in Figure 5. Crease lines were made to facilitate bending movements at the waist and back. A notable benefit of the structure of the inlaid knitting became evident as the portions of the inlaid fabric remained connected by the yarn even after the inlaid foam rods were cut (Figure 6). Due to the longitudinal arrangement of the inlaid material at the waist panel (Figure 5), the panel can bend to the desired curvature without springing back (Figure 7). This bolstered the comfort and fit of the knitted buoyant swimming vest and also improved the fit and hardness of the conventional buoyant vest with foam blocks as the buoyant media, according to Table 1.

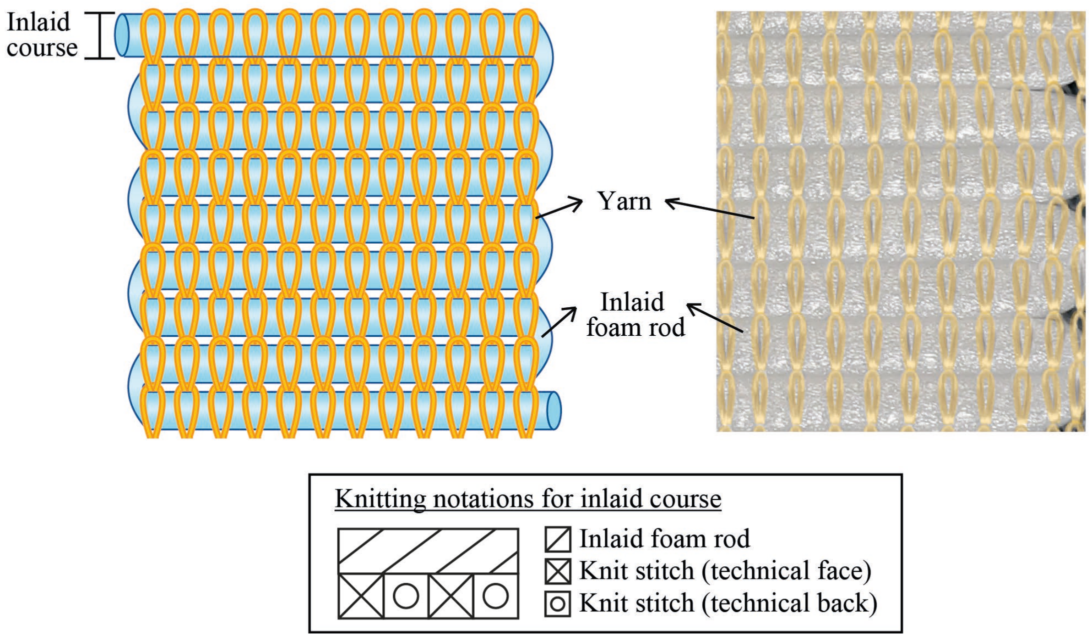


Figure 3. Structural details of the inlaid knitted fabric

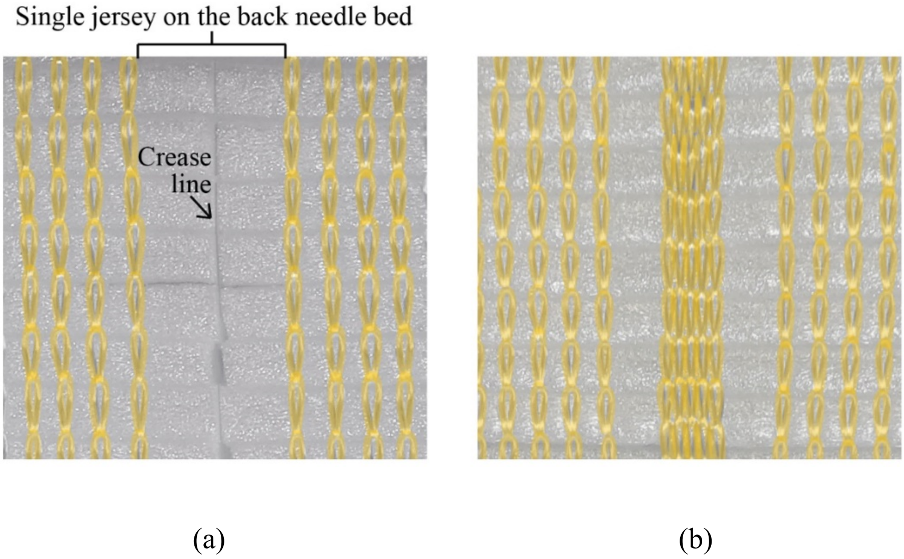


Figure 4. Image of the crease line at back panel: (a) front view; (b) back view

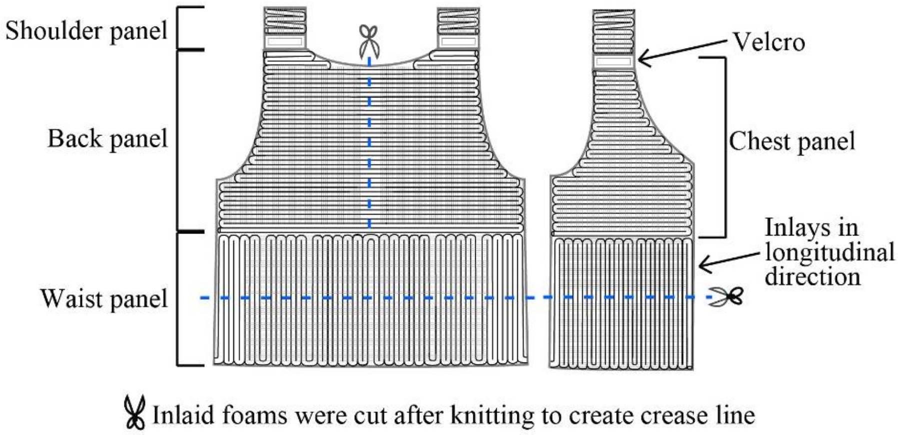


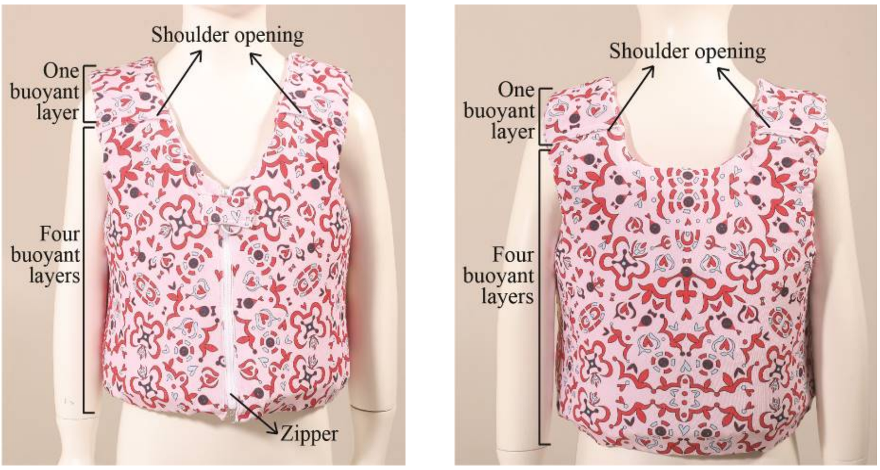
Figure 5. Creation of crease line on inlaid knitted buoyant layer

Figure 6. The crease line of the waist panel, created by cutting

Figure 7. The shape retention property of inlaid knitted fabric

3.1.2 Construction of prototype

A knitted buoyant swimming vest with a shell was developed (Figure 8). It was a V-neck vest composed of four buoyant layers in the body panel and one layer in the shoulder panels. The knitted vest was developed to match the size of two market samples for comparison.

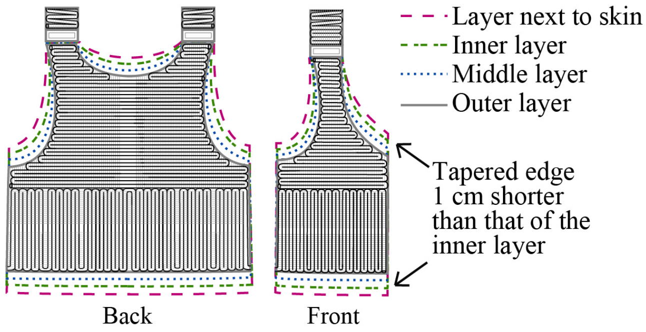


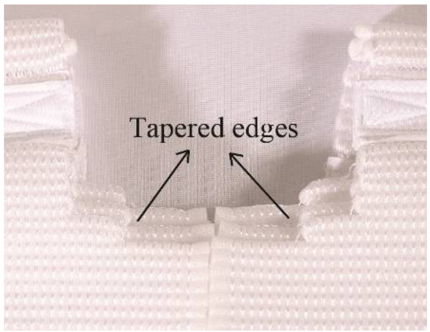
(a) (b)

Figure 8. The knitted buoyant swimming vest: (a) front view and (b) back view

3.1.2.1 Adjustable buoyancy and tapered edges

The knitted buoyant layers can be removed individually to enable a range of buoyancy adjustment as the wearer's swimming skills develop. Velcro was sewn to the shoulder panels to connect the front and back panels. The edges of the knitted buoyant fabric at the armholes, neckline and hem tapered to a length 1 cm shorter than that of the inner layer (Figure 9). In line with the Kim et al.[30] study, the reduction in the garment's outer length facilitated the wearer's movement.





(a) (b)

Figure 9. (a) Illustration of the outer and inner inlaid knitted buoyant layers with tapered edges; (b) image of the tapered edges at the back of the neckline

3.1.2.2 Shell of the knitted buoyant vest

The shell was fabricated with one end of 75D/72F 100% polypropylene and one end of 20/20 100% nylon/lycra in single jersey. A Santoni SM8- TOP2 (Lonati Group, Italy) circular knitting machine with gauge 28 was used. The openings located at the front and back of the shoulder panels and at the hem were developed for the removal of the knitted buoyant fabric inside the shell. The graphic print was created using Adobe Photoshop CC and printed with a benchtop UV flatbed printer (VersaUV LEF-200, Roland DGA Corporation, US). Pink, pale yellow and red were used as the main colours, with navy and baby blue acting as highlights.

3.2 Evaluation and wear trial

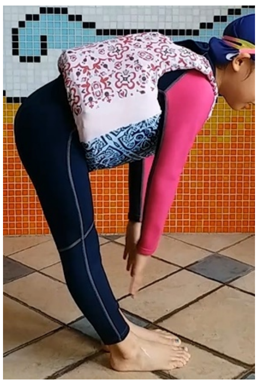
Both objective and subjective measurements were taken to evaluate the knitted buoyant vest with two market samples. Safety is a major concern in the production of a functional buoyant swimming vest. Therefore, the objective evaluation of the knitted buoyant vest and the two market samples was conducted according to BS EN13138-1:2014.[31] Input from children provided the subjective measurements used to assess the performance of knitted buoyant vest. The Functional, Expressive, and Aesthetic (FEA) Consumer Needs Model was employed in the development of the questionnaire used to collect this information.

3.2.1 Objective measurement

A series of laboratory tests including tests of buoyancy (Clause 5.2) and the mechanical properties of the materials (Clause 5.5) were conducted in accordance with the procedures stated in ISO 12402-9:2006.[32] Prior to testing, each sample was soaked for at least five minutes in fresh water. For the buoyancy test in Clause 5.2, the garment was enclosed in the standard cage with a weight attached. The cage was suspended in the water at a temperature of 20 ± 5°C from the load cell so that the upper surface of the horizontally positioned garment was submerged 100 to 150 mm below the water surface. The assembly was immersed for 24 ± 0.5 hours, and its weight was recorded as A. The cage was immersed without the garment, and its weight was recorded as B. The buoyancy was obtained by deducting A from B. According to the British Standard EN13138-1:2014,[31] a buoyant garment made for swimming must have a minimum buoyancy of 20N for a wearer with 18 to 30 kg body mass aged between 3 and 6. When testing the mechanical properties in Clause 5.5, the material sample should lose no more than 10% of its original buoyancy. Three garment samples for each type of buoyant swimming vest were used in the standard buoyancy test.

3.2.2 Subjective measurement

User needs were realised through personal interviews and participant observation, which led to the further development of design criteria to provide human-oriented design.[33-35] It is common to use data from participant observation and visual documentation when studying children's behaviour and needs.[34, 36, 37] The participants were caregivers of children, such as teachers, chosen for their understanding of the users' needs. Their input was incorporated with that of experienced designers to translate users' needs into relevant attributes.[34] Test subjects were asked to performed several types of movement in and out of water while wearing the buoyant vest.[30] Each type of vest was tested once with each subject. The tests were conducted in an indoor swimming pool with a depth of 1.1 m with an air temperature of 32°C and a water temperature of 34°C. Before testing in water, each subject was told to perform three types of movement, including shoulder joint flexion, extension, adduction, abduction and hyperadduction; waist flexion and extension, sitting and standing (Figure 10a). Abduction of the arm is a movement away from the midline of the body, and hyperadduction is the movement of the arm beyond its accustomed position and towards the midline of the body.[38] Subjects were then required to swim along the length of the pool for 4 m, to swim along the width for 5 m and to perform a self-rotating movement (Figure 10b). A short personal interview was conducted to ascertain subjects' satisfaction concerning their comfort regarding the tightness of the buoyant vest. The process of the wear trial was recorded with a digital camera in video for visual analysis by two professional observers, being a professional swimming instructor and a research team member.



(a)

(b)

Figure 10. Wear trial: wearing knitted buoyant vest (a) out of water in waist flexion position; (b) in water

3.2.2.1 Subjects

Approval for this study was obtained by the Ethics Committee, as was informed consent from all parents prior to the experiments, according to protocol. Twelve subjects were recruited to evaluate the buoyant vests, these being four boys and eight girls with an average age of 5.04 years (SD: 0.81), height of 112.71 cm (SD: 7.83) and weight of 18.22 kg (SD: 4.11). Participants reported an average time of eight months required to learn to swim (SD: 4.20). The details of the subjects' body measurements are listed in Table 2.

Table 2. Body measurements of subjects in wear trial

Measurement	Mean	SD
Height (cm)	112.71	7.83
Weight (kg)	18.22	4.11
Shoulder width (cm)	27.75	1.82
Neck circumference (cm)	26.08	1.00
Chest circumference (cm)	56.00	2.44
Waist circumference (cm)	52.50	2.82
Waist back length (cm)	25.50	4.25
Waist circumference (Omphalion) (cm)	54.04	2.73
Waist back length (Omphalion) (cm)	29.33	2.35

3.2.2.2 Questionnaire

The questionnaire was developed based on the published functional apparel studies and the FEA Model.[30, 39-43] The FEA model was developed by Lamb and Kallal (1992) to assess functional, expressive and aesthetic considerations to identify the consumer needs.[44] The FEA model's has been widely used in the functional garment studies such as sailing apparel, tennis wear, climbers' pants and clothing needs of adolescent girls with disabilities.[39, 41, 45, 46] The aspects of fit, protection, mobility, comfort and donning and doffing are primary consideration, besides, the aesthetic and expressive consideration are less crucial for functional apparel.[39] The wearer's perception of fit is derived from how a garment conforms to the body, along with its functionality. It is subjective based on the wearer's body shape, size and cultural influences.[39, 47, 48] The comfort of the garment is related to the textile used, garment fit, stiffness or pressure against the body. Sensorial and thermal comfort have been the main foci for most researchers.[49, 50] Improper fitting or restricted movement of functional garments adversely affect the garment's protection of the wearer and may even contribute to injury.[39] Therefore, the functional criteria of the FEA model including fit, mobility, comfort and donning and doffing were employed as the basis for the questionnaire. The wearer's confidence level was also included in this study to investigate the effect of buoyant vests on the improvement of their confidence in water.

Three types of buoyant vest were evaluated in three stages of evaluation of the buoyant vest design regarding (a) fit, (b) comfort and (c) mobility. Feedback from the participants was obtained by using a five-point Likert scale (1 = extremely dissatisfied to 5 = extremely satisfied). To measure the tightness of the vest, a 5-point rating scale was used in which 1 signified ‘too loose’, 2 ‘loose’, 3 ‘moderate’, 4 ‘tight’ and 5 ‘too tight’. The analysis of fit is modified from previous literature, including (1) fitting of neck, (2) fitting of shoulder, (3) fitting of waist, (4) overall fit and (5) overall tightness.[30, 39-41] To analyse the satisfaction of comfort, the questionnaire included (1) the ability to retain warmth, (2) stiffness of garment, (3) overall comfort and (4) the level of confidence while swimming in water with the buoyant swimwear.[39, 42, 43] Satisfaction regarding the displacement of the vest from the shoulder due to buoyancy was also evaluated.[30] The evaluation of mobility included the freedom of arm movement, waist movement and swim movement, as well as the ease of donning and doffing after swimming.[30, 39]

3.2.3 Statistical analysis

The data from the subjective wear trial experiment were analysed with SPSS 23 (IBM Corp., Armonk, New York). Before conducting the paired-sample t-test and repeated measures analysis, an intraclass correlation coefficient (ICC) was used to examine the reliability of the rating scores. The differences in the rating scores from twelve subjects based on a mean rating (k = 12), absolute-agreement and a two-way random-effects model were examined. A high degree of reliability was found between the subjects' rating scores. The average ICC (2,12) was .89 with a 95% confidence interval from .84 to .92 ($F_{(65,715)} = 9.81$, $p < .001$). A paired-sample t-test was conducted to analyse any significant differences between the tightness value in and out of water. A repeated measures analysis of variance (RANOVA) was conducted to compare the ratings of satisfaction between the dependent variables (satisfaction of fit, comfort and mobility) and the independent variable (types of buoyant vests). Prior to the repeated measures analysis, the data were screened to ensure that the test's assumptions were met. Descriptive statistics, histograms, Q-Q plots and the measures of skewness and kurtosis indicated that the distribution of the dependent variables was close to a normal curve. The assumption of sphericity and equality of variance was fulfilled. The significance level of the statistical analysis was set at 0.05.

4. Result and discussion

The physical properties and the buoyancy of the knitted buoyant swimming vest and the two market samples are listed in Table 3 and 4. The satisfaction ratings and results of the repeated-measures ANOVA of the wearers' satisfaction regarding the fit, comfort and mobility of the buoyant swimming vests are listed in Table 5.

Table 3. Physical properties of knitted buoyant vest and market samples

Measurements	Knitted buoyant vest	Market sample A	Market sample B
Buoyant media	Inlaid knitted fabric	Foam board	Foam rod
EPE foam material	Removable	Integral	Removable
Number of buoyant foams	4 layers	4 layers	8 rods
Garment weight (g)	226.80	230.51	261.94
Garment thickness (cm)	6.0	5.5	8.0
Density of foam (kg/m^3)	19.61	16.50	21.92

Table 4. Results of the buoyancy test according to British Standard EN13138-1:2014[31]

Clause	Testing item	Results		
		Knitted buoyant vest	Market Sample A	Market Sample B
5.2	Buoyancy			
5.2.1	Buoyancy characteristics of the complete device	Pass	Pass	Pass
	Buoyant force of the complete device (N)	30.9	27.8	25.8
5.5	Materials - mechanical properties			
5.5.2	Resistance to puncturing	Pass	Pass	Pass
	Buoyancy loss (%)	6.5	6.0	5.2

Table 5. Results of satisfaction ratings and the repeated-measures ANOVA of the knitted buoyant vest and market samples

Condition	Category	Evaluation	Knitted Buoyant Vest Mean	SE	Market Sample A Mean	SE	Market Sample B Mean	SE	*F*	*Sig.*
Out of water	Fit	Neck	3.92	0.31	3.58	0.26	3.42	0.23	1.32	0.31
		Shoulder	4.08	0.31	3.50	0.26	3.50	0.20	3.13	0.09
		Waist	3.75	0.28	3.58	0.19	2.00	0.28	17.64	0.00
		Tightness[a]	2.67	0.19	2.58	0.15	4.58	0.19	40.79	0.00
		Overall fit	3.75	0.31	3.50	0.29	2.17	0.27	5.62	0.02
	Comfort	Warmth	4.00	0.25	3.92	0.23	3.67	0.14	0.56	0.59
		Stiffness	3.92	0.23	3.50	0.26	2.17	0.37	9.40	0.01
		Overall comfort	4.33	0.26	3.67	0.19	2.00	0.28	10.68	0.00
		Confidence in water after wear	4.00	0.21	3.58	0.19	3.75	0.13	3.79	0.06
	Mobility	Freedom of arm movement	4.67	0.14	4.17	0.11	3.67	0.19	10.71	0.00
		Freedom of waist movement	4.50	0.15	4.00	0.25	2.58	0.43	7.79	0.01
In water	Fit	Neck	3.42	0.29	3.17	0.30	3.50	0.20	0.46	0.65
		Shoulder	3.50	0.26	3.42	0.23	3.50	0.20	0.10	0.91
		Waist	3.00	0.25	3.42	0.23	2.75	0.22	2.30	0.15
		Tightness[a]	2.17	0.11	2.33	0.23	4.42	0.19	74.78	0.00
		Displacement of vest from wearer's shoulders due to buoyancy	2.75	0.22	2.58	0.29	3.75	0.22	4.20	0.05
		Overall fit	3.00	0.21	2.83	0.27	2.58	0.26	0.94	0.42
	Comfort	Warmth	3.75	0.28	3.58	0.19	3.58	0.19	0.22	0.81
		Overall comfort	4.00	0.28	3.33	0.28	2.17	0.37	15.28	0.00

	Confidence in water after wear	4.50	0.15	3.92	0.15	3.92	0.15	7.42	0.01
Mobility	Freedom of swimming	4.42	0.15	3.67	0.23	3.58	0.19	18.08	0.00
	Ease of donning and doffing	4.67	0.14	4.00	0.17	3.25	0.25	15.73	0.00

Notes: Five-point Likert scale (1 = extremely dissatisfied, 5 = extremely satisfied)

[a] A rating of 1 signifies ‘too loose’, 2 ‘loose’, 3 ‘moderate’, 4 ‘tight’ and 5 ‘too tight’.

4.1 Objective measurement - Standard buoyancy test

The results revealed that the knitted buoyant vest and the two market samples passed the minimum buoyancy requirement (Table 4). The knitted buoyant vest had the highest buoyancy, 20 per cent higher than that of Market Sample B. Archimedes’ principle states that a body immersed in fluid experiences a buoyant force equal to the weight of the fluid it displaces.[51] For an object with less density than that of water, the weight of the object is less than the weight of the same volume of water. The object cannot displace enough water to become completely submerged, and thus only a part of it is submerged in the water, making it float.[52] When an object floats, the gravitational force acts in the downward direction while the force of buoyancy acts on the object in an upward direction.[53] An object with the same volume but a lower weight has a higher net buoyant force. As these three vests are the same size, the buoyancy of the vest depends on the density of the foam, the amount of foam in the vest and the weight of the vest.

The density of the foam in Market Sample B was the highest among the three vests (Table 3); therefore, Market Sample B had the lowest net buoyant force. However, the foam density and net buoyant force of Market Sample A was lower than that of the knitted buoyant vest. As Market Sample A and the knitted vest were of similar thickness and had the same number of foam layers, this difference may be explained by the use of neoprene in the shell of Market Sample A. Although tiny bubbles enclose air in neoprene,[54] the buoyancy provided by this effect was less significant than its increased weight, which lowered the vest's buoyancy. Consistent with the buoyancy principle, the knitted buoyant vest had the lowest weight and highest buoyancy among the three vests. The knitted shell reduced the garment weight, compared with the neoprene shell used in the market samples. The lower weight and foam density of the knitted vest increased its buoyancy to 20% higher than that of market sample B. The thickness of Market Sample A and the knitted vest were lower than that of Market Sample B. The results of this test imply that the knitted buoyant vest improved on the buoyancy and bulkiness of the conventional swimming vest.

4.2 Subjective measurement

4.2.1 Fit satisfaction

The results of the repeated-measures ANOVA show an overall significantly higher level of satisfaction with the knitted buoyant vest than with Market Sample B in terms of waist and overall fit out of water (Table 5). This may be explained by considering that buoyant inlaid knitted fabric retains the body shape of the wearer and improves the overall fit. However, no significant difference was found between the knitted buoyant vest and Market Sample A in these criteria, which shows that it has the same high satisfaction as Market Sample A. Upon measurement of the displacement of each buoyant vest from the wearer's shoulders when swimming, the knitted buoyant vest elicited no significant difference in satisfaction level than Market Sample A, the level of which was lower than that of Market Sample B. This result may be explained by the tight fit of Market Sample B, which tended to be too tight according to wearers' reviews; this prevented the buoyant vest from displacing away from the body. In terms of neck fit, shoulder fit, waist fit and the overall fit in water, there was no significant difference reported between the knitted buoyant vest and the two market samples, which shows that the knitted vest yielded the same high satisfaction as the market samples.

For the tightness of the swimming vest, the results of the paired-sample t-test show an overall significant difference between the tightness of the three buoyant vests when worn in and out of water (t_{35} =2.743, $p<.05$). Participants in this study reported that all three buoyant vests were tighter out of water (mean = 3.28, SE = 0.19) than in water (mean = 2.97, SE = 0.20). On average, the tightness rating of the vest when worn out of water is 0.31 points higher than that of the vest when worn in water (95% confidence interval [0.08, 0.53]). This can be explained by the sensation of weakened gravitational pull in water, the effect of which is that body fat evenly distributed around the body of the wearer and the wearer felt thinner in water than out of water. An overall significant difference was found between the degree of tightness of the knitted buoyant vest and Market Sample B both in and out of water ($p<.001$). Participants in this study reported that the knitted buoyant vest (out of water: mean = 2.67, in water: mean = 2.17) was a moderate fit tending towards looseness and that Market Sample B (out of water: mean = 4.58, in water: mean = 4.42) was a tight fit tending towards being too tight. Feedback on the knitted buoyant vest did not differ significantly from feedback on Market Sample A. The tightness of the swimming vest was related to wearer's satisfaction with its comfort, which will be discussed in the next section.

4.2.2 Comfort satisfaction

Participants in this study were significantly more satisfied with the overall comfort of the knitted buoyant vest, both in and out of water (out of water: mean = 4.33, in water: mean = 4.00), followed by Market Sample A (out of water: mean = 3.67, in water: mean = 3.33) and then Market Sample B (out of water: mean = 2.00, in water: mean = 2.17). Participants reported that the knitted buoyant vest was the most comfortable vest both in and out of water, followed by Market Samples A and B. These results may be explained by considering that the tightness of Market Sample B made the wearer feel uncomfortable when wearing it, even though it exhibited the least displacement from the body. The comfort afforded by the knitted vest may also be due to its soft-knitted shell fabric, which provides better hand feel and comfort to the wearer than that of neoprene used in the market samples. According to previous studies, the handle of the fabric was not significantly altered by the UV-cured ink layer in the KES measurements.[28, 55, 56] It was anticipated that the print on the shell fabric would have a little impact on the overall comfort. Moreover, the wearer reported that the knitted buoyant vest and Market Sample A were more comfortable to wear out of water than in water. This may be explained by the displacement of the vest due to buoyancy when worn in water, which lowers the wearer’s comfort level. However, Market Sample B yielded higher overall comfort in the water than when worn out of water. This may be because the wearer felt the fit of Market Sample B to be looser and more comfortable when it was worn in water. According to Table 5, participants reported higher confidence in water by 0.58 points while wearing the knitted buoyant vest in water than they did wearing Market Samples A and B. This implies that the knitted buoyant vest improved the wearer's confidence in water better than the market samples. The wearer's confidence in water after wearing the buoyant vest out of water and their satisfaction regarding its warmth retention did not differ significantly between the knitted buoyant vest and the two market samples.

4.2.3 Mobility

Participants reported the highest levels of satisfaction in freedom of arm movement out of water, freedom of swimming and ease of donning and doffing after wearing the knitted buoyant vest in water, followed by Market Sample A and Market Sample B (Table 5). This may be because the tapered edge of the buoyant layer in the knitted buoyant vest facilitated arm movement when compared with Market Samples A and B, the design of which affected freedom of swimming. The tightness of Market Sample B increased the difficulty of donning and doffing, which resulted in lower satisfaction than that resultant from Market Sample A and the knitted buoyant vest. Moreover, wearer satisfaction regarding waist movement while wearing the knitted buoyant vest (mean = 4.50, SE = 0.15) was 1.92 points higher than that associated with Market Sample B (mean = 2.58, SE = 0.43) and elicited similar satisfaction to Market Sample A. This may be because the crease lines in the knitted buoyant layer inside the knitted buoyant vest facilitated bending of the waist, as opposed to the bulky foam rod in Market Sample B. The results show that the knitted buoyant vest has significantly improved on the mobility afforded by conventional buoyant vests in terms of the freedom of arm and waist movement, the freedom of swimming and the ease of donning and doffing.

5. Conclusion

The knitted buoyant swimming vest was developed to have a better fit, greater comfort and increased mobility for recreational swimming. When comparing knitted buoyant vest with the two market samples, the knitted buoyant vest exhibited the highest buoyancy and highest satisfaction in overall comfort and confidence in the water, ease of arm movement and ease of swim movement. The knitted buoyant vest yielded higher satisfaction in overall fit out of water than Market Sample B due to the shape retention of the knitted buoyant fabric in its vest. The tapered edges of each knitted buoyant layer and the crease lines in the vest facilitated swim movement and bending at the waist. The multi-layer feature of knitted buoyant vests also allows flexibility in that the buoyancy can be adjusted by removing buoyant layers as the wearer's swimming ability improves. The wearers also commented that the buoyant vests feel looser when worn in water as opposed to out of water. The results of the study show that the design of the conventional buoyant swimming vest was significantly improved by the development of the knitted buoyant vest in terms of fit, comfort and mobility. In future, the function of adjustable fit should be studied when considering the fit of a buoyant swimming vest on the wearer's body.

Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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