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RESEARCH

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"Float First": Trapped Air Between Clothing Layers Significantly Improves Buoyancy After Immersion

Martin J. Barwood, Victoria Bates, Geoffrey Long, and Michael J. Tipton

Approximately 450,000 people drown annually worldwide. The capacity of immersed adults and children to float in clothing is less well understood, but it is possible that air trapped between clothing layers increases buoyancy. These studies aimed to quantify buoyancy and the practical implications thereof. Study 1 (n = 24) quantified this buoyancy and the consequence of any buoyancy by measurement of airway freeboard (mouth to water level distance). Study 2 examined the capability of children (n = 29) to float with freeboard used as the outcome measure and is expressed as a percentage of occasions that freeboard was achieved. Buoyancy (measured in newtons; N) was provided for winter clothing as 105(± 12)N, for autumn/spring clothing as 87(± 13)N, and for summer clothing as 68(± 11)N. In all cases, buoyancy was greater than for the control condition of 61(± 11)N. Average freeboard was 63(± 2) % for winter clothing, 62(± 2) % for autumn/spring clothing, 66(± 2)% for summer clothing, and 15(± 1)% for the control condition. Children were more buoyant, 95(± 17)% freeboard, irrespective of gender, than adults. "Float first" is advocated as a primary survival mechanism.

Keywords: Floating, freeboard, cold shock, drowning

An average of 445 people per annum drown in the UK (Royal Society for the Prevention of Accidents, 2002, 2005). The majority of these drowning incidents occurred in inland rivers and streams or in the relatively calm waters of lakes and reservoirs. Many of the victims were young, who had accidentally fallen into the water, were fully or partially clothed, and drowned within a short distance of the safe refuge of land. Indeed, data from the International Lifesaving Federation (International Lifesaving Federation, 2010) suggest that approximately 40% of drownings occur within 2 m of safety and a quarter occur in water less than 1 m deep. These data suggest that swimming performance in the early minutes of immersion is impaired. This, in part, is due to the low average annual water temperature in and around the U.K where temperatures reach a nadir of ~6 °C in spring and a peak of 16 °C in autumn throughout the yearly cycle (Lowestoft et al., 2007-2008). Even

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with the partial protection provided by clothing, immersion into water throughout this range of temperatures impairs swimming performance (Tipton, Eglin, Gennser, & Golden, 1999), may cause anxiety (Barwood, Dalzell, Datta, Thelwell, &Tipton, 2006; Barwood, Datta, Thelwell, & Tipton, 2007), and induces hazardous cardio-respiratory responses (Tipton, Stubbs, & Elliott, 1990; Tipton, 2003).

The physiological responses during the first few minutes of cold water immersion (CWI) are well understood and have been studied extensively (Barwood et al., 2006, 2007; Datta & Tipton, 2006; Tipton, Eglin, & Golden, 1998; Tipton, Golden, Higenbottam, Mekjavic, & Eglin 1998). They have been described collectively as the "cold shock" response (Tipton, 1989) and characterized by an "inspiratory gasp," hyperventilation, tachycardia, peripheral vasoconstriction, and hypertension. The hyperventilatory component of the cold shock response makes coordinating breathing during swimming difficult and significantly decreases maximum breath-holding time (Barwood et al., 2006). Thus, during the early minutes of immersion, there is an increased risk of aspirating water and drowning (Tipton, 1995). This represents a further hazard in addition to that posed by the high cardiovascular strain (Tipton, 2003). The "cold shock" response declines after the first three minutes of immersion as the cutaneous cold sensitive thermoreceptors adapt to the cold water (Mekjavic & Bligh, 1989). Following this adaptation, heart rate and breathing frequency return toward preimmersion levels and swimming a short distance may become possible (Ducharme & Lounsbury, 2007). Therefore, even in calm water, attempts to swim while experiencing cold shock may result in drowning. The current experimental evidence supports not attempting to swim (i.e., floating if possible) for a period of two to three minutes upon CWI to regain control over breathing (Ducharme & Lounsbury, 2007; Golden, Hardcastle, Pollard, & Tipton, 1986). Golden et al. (1986) demonstrated that swim failure within ten minutes was more likely on cold water immersion (5 °C) if participants, who were competent pool swimmers, began to swim immediately; swim failure did not occur if participants rested in the water for two minutes before beginning to swim.

Some drowning accidents may also be attributable to a lack of basic swimming skills and appropriate survival behavior. The existing standards for teaching people to swim are primarily focused on achieving the correct swimming technique for performance and to a lesser extent on achieving basic survival skills that are specific to cold water (Swim Teachers Association, 2010). Within the swim teaching curriculum, floating is encouraged to maintain buoyancy if accidentally immersed in water by means of making a flotation device from an item of clothing (e.g., tying knots in the legs of a pair of trousers) or lying supine in the water (Swim Teachers Association, 2010). There is currently no evidence basis for floating or the use of inherent buoyancy as a survival strategy. If adopted, this approach would be complementary to the suggestion that it is advisable to remain still (i.e., float if possible) for the first minutes of immersion while the cold shock response subsides (Golden et al., 1986; Ducharme & Lounsbury, 2007). It has already been suggested, but not investigated, that trapped air between clothing layers may provide some buoyancy to immersed victims (Golden & Tipton, 2002; Tipton et al., 1990), but swimming (or actions such as waving for help) may release the air trapped within the clothing, thereby reducing the freeboard (distance between water level and victim's mouth) of the immersed victim and increasing the chances of submersion of the airway and

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drowning. It appears that the behavior during the initial minutes of accidental cold water immersion can be critical in determining survival prospects and a policy of "float first" during this period could improve survival prospects. This approach is counter-intuitive, however, and has not been empirically investigated; it therefore currently lacks an empirical evidence base.

This study aimed to examine the possibility that an immersed victim may be aided by buoyancy provided by air trapped between clothing layers during the initial minutes of immersion. A laboratory study was conducted to establish the buoyancy associated with three different seasonal clothing assemblies in adults, and one field-based (swimming pool) study was conducted to establish the practical significance (i.e., did any inherent buoyancy enable the airway to remain clear of the water and to maintain freeboard) of any clothing buoyancy for children and adolescents.

The experimental hypotheses for study 1 (adult participants) were that (a) there would be significant buoyancy provided by air trapped between clothing layers, (b) buoyancy would increase with the number of clothing layers, and (c) the buoyancy of the participant would be influenced by the experimental manipulation of swimming in comparison with floating. The experimental hypothesis for study 2 (child and adolescent participants) was that any buoyancy provided by clothing would enable children and adolescents to float and that swimming compared with floating would decrease buoyancy.

Method: Study 1

Participants

The study was approved in advance of data collection by the University of Portsmouth Biosciences Research Ethics Committee. All participants provided written and informed consent to participate. All participants were screened to ensure they were fit to complete the study and provided health history information. Each participant underwent a medical examination and a 12 lead electrocardiogram was taken, inspected, and approved by a qualified independent medical officer. The physical characteristics of participants in study 1 are reported in Table 1.

Table 1 Mean (SD) Participant Characteristics for the Male and Female Adults Who Completed Study 1

	Age (Years)	Height (m)	Mass (kg)	Skinfold (mm)	Body Fat (%)
Overall (n = 24)	21 (3)	1.73 (0.1)	71.2 (11.4)	47.0 (18.4)	21.5 (8.4)
Adult Males (n = 12)	22 (3)	1.78 (0.1)	75.7 (9.7)	34.2 (8.6)	14.0 (3.0)
Adult Females (n = 12)	21 (3)	1.69 (0.1)	66.8 (11.6)	59.9 (16.5)	29.0 (4.0)

Experimental Design

Participants visited the laboratory on one occasion, where they completed a total of seven submersions in a counter-balanced order in a swimming flume containing chlorinated thermoneutral water (35 °C). Six of the submersions took place in different clothing assemblies reflecting the "typical" clothing worn in winter, spring/autumn, and summer; for the remaining submersion, the participants wore a bathing costume only, which acted as the control condition. The order of conditions was determined using a Latin square procedure. The estimated clothing insulation (CLO) of each clothing assembly was 1.1, 0.7, 0.2 and > 0.1 for the winter, spring/autumn, summer, and control conditions, respectively; 0 CLO corresponds to a naked individual and 1 CLO is $0.155m^2$ KW equivalent to a typical business suit.

The participants completed two experimental manipulations in each of the three clothing conditions. Each manipulation was preceded and followed by a subjective observation of floating position and objective quantitative measurements of buoyancy using underwater weighing. The subjective observations were included to demonstrate face validity to the procedures, whereas the buoyancy measurement was included to reliably quantify buoyancy. The two manipulations were a two-minute "float only" condition and a two-minute controlled swim. In the control condition, it was assumed that buoyancy would be unchanged by floating, compared with swimming and therefore only the float condition was conducted. Figure 1 indicates the order and timing of the measurements taken as part of study 1.

Experimental Procedure

The timing of all data collection (i.e., initial buoyancy measurement, start and end of swimming period, second buoyancy measurement) was closely matched to avoid temporal variation between test conditions. Each test lasted approximately five and a half minutes in total. The participants dressed in the first clothing assembly and entered the environmental chamber. Subsequently, they sat on an immersion chair attached by a chain to an electronic winch (CPM, F1–8; 2–8; 5–4, Yale, Shropshire, U.K) with a calibrated strain gauge (Biometrics Ltd, VA, USA) in series of the chain. The strain gauge was zeroed before each test with the chair attached. Therefore the participants' weight and its change with submersion were recorded during each test.

Before each test, the participants securely fastened a seat belt equipped with a release button before being winched above the swimming flume. The procedural requirements of the participants were then reiterated, and they were lowered, at a reproducible rate ($8m \cdot min^{-1}$), into still water to the level of the most buoyant part of the clothing assembly above the head (i.e., hood); this took ~23 s. Following a maximal inhalation, the participants held their breath before entering the water; the volume of the maximum inhalation was measured before the first submersion test (see measurements section below). Following submersion, the chair was steadied and a measurement of mass was recorded for ~20 s. If the participants were unable to breath hold for 20 s, a shorter duration was selected; three female participants chose to breath-hold for 15 s. At the end of the 20 s period the participants were winched back up to shoulder level and released the seatbelt, moved away from the chair, and lay floating on their back for 20 s. It was noted whether the airway remained clear of the water and if the participants needed to paddle to achieve a floating position (assessment of freeboard). Subsequently, and depending on the

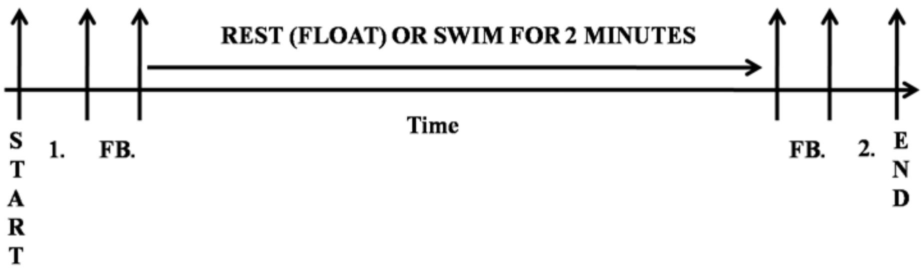

Figure 1 — Order and timing of the measurements taken in study 1. Points 1 and 2 denote buoyancy measurements 1 and 2. FB denotes the points at which freeboard was estimated. Either resting (floating) occurred between FB measurements (condition dependent). Study 2 used a similar measurement order but did not include buoyancy quantification (points 1 and 2).

test manipulation, the participants either remained still and floated for a further two minutes or turned on to the front and swam (breaststroke) against a gentle current generated by the swimming flume for two minutes at a speed of $0.5 m \cdot s^{-1}$, which was equivalent to a distance of ~60 m. At the end of this two-minute period, the participants either remained still for a further 20 s (float manipulation) or moved onto the backs (swim manipulation) for a further assessment of freeboard. The participants then sat back on the immersion chair and a further measurement of buoyancy was made (submersion to the same depth as in buoyancy one measurement) by underwater weighing.

Finally, the participants were winched from the immersion pool and undressed to their bathing costume. The participants dried with a towel and redressed in dry clothes in preparation for the next condition. The difference in underwater weight before and after the interventions, and in comparison with the control (swim suited) submersions, was used to indicate the amount of air (buoyancy) lost in the clothing. On one occasion, a measure of body composition was made (see below) in the period between tests.

Each clothing assembly was based on the insulation required to keep individuals warm in the average temperature conditions of the different seasons. They comprised the following:

1. Control condition: a normal bathing costume (i.e., close fitting trunks or female bathing costume); one test: control (CON)
2. Summer condition: trainers, knee length cotton shorts, and a t-shirt tucked into the waistband of the shorts. Two tests: summer float (SF) and summer swim (SS)
3. Autumn/spring condition: trainers, jeans, a t-shirt, and a long sleeve cotton shirt tucked into the waistband of the trousers and a waterproof/windproof jacket with the hood down. Two tests: autumn/spring float (A/SF) and autumn/spring swim (A/SS)
4. Winter condition: trainers, jeans, long-sleeve cotton shirt, a woolen jumper, and a waterproof/windproof jacket with the hood up. Two tests: winter float (WF) and winter swim (WS)

Measurements

The primary measure was the underwater weight of the participants on initial submersion and after the period of floating or swimming. The underwater weight was measured by a load cell (Biometrics Ltd, VA, USA) located in series with the winch support chain. The load cell was accurate to 100 g. The calibration process involved hanging certified weights from the load cell and verifying accuracy. Strain gauge data were recorded continuously throughout buoyancy measurement at a frequency of $1 \cdot s^{-1}$ (Biometrics data logging system, Biometrics Ltd, VA, USA).

The volume of each participant's maximum inhalation was measured in air while adjacent to the swimming flume and assumed to be the same volume as the breath taken just before the participants were submerged. It was measured while seated in a chair and breathing through a two-way Hans-Rudolph mouthpiece connected to a piece of respiratory tubing attached to a spirometric transducer (Spirometric transducer module, KL Eng. Co., Northridge, USA). After breathing normally, participants took a maximal inhalation and the volume was recorded. Each participant performed this maneuver on three consecutive occasions. After this, their vital capacity (VC; the maximum amount of air that could be expelled from the lungs after a maximal inhalation) was also measured using the same equipment. The average of three attempts was again calculated.

A qualitative measurement of the consequence of any inherent buoyancy was made by assigning a fixed value of 1 to participants whose airway remained clear of the water without paddling, 0.5 if the airway remained clear of the water with minimal paddling, and zero if the participant's airway was consistently submerged requiring significant paddling to float.

Participants completed an anthropometric profile of skinfold thickness at four different sites (bicep, tricep, subscapular, iliac crest). Measures were taken in duplicate by an accredited anthropometrist. These data were used to estimate body composition (body fat percentage) using a sum of four skinfolds, which will contribute, in part, to interindividual variation in buoyancy. The equations of Durnin and Womersley (1974) were used to estimate fat percentage in adults based on the assumptions of the Siri equation (Siri, 1961).

Data Analyses

The data generated by the biometrics load device (in kilograms) were converted to Newtons by multiplying by 9.81. A mean (*SD*) value for buoyancy was calculated for the 20 s period preceding (i.e., buoyancy measurement 1) and following (i.e., buoyancy measurement 2) resting and swimming for each clothing condition. Data were then compared using an analysis of variance (ANOVA) with repeated measures for buoyancy change (a) as a consequence of swimming compared with floating, (b) between genders, and (c) between clothing assemblies. Assumptions of sphericity were checked using Mauchly's test. Where nonspherical data sets were evident, a Greenhouse-Geisser adjustment was used.

To establish the practical significance of any inherent buoyancy, the freeboard data were converted to a percentage by dividing the value assigned (0, 0.5, or 1) by the number of occasions the participants were asked to take the freeboard position in study 1: 6 clothing assemblies, two tests (swim vs. float) plus two Control tests, a total of 14 occasions; study 2: 1 clothing assembly, two tests (swim vs. float), a total of 4 occasions. Percentage freeboard was calculated for each cloth-

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ing assembly, manipulation, and time point using the data collected in study 1 and were compared between gender.

To assess the relationship(s) between the freeboard data following the first buoyancy measurement and the measured respiratory and anthropometric variables that may influence buoyancy, a Pearson's correlation was calculated for the winter and control conditions. The alpha level for all statistical tests was set at 0.05

Results

The data indicated that (a) a significant amount of air (causing buoyancy) was trapped underneath the layers of clothing during submersion ($p = .001$; Figure 2). This averaged 25 (± 16) N across conditions for buoyancy measurement 1; (b) this buoyancy declined over time ($p = .001$; Figure 2) to 10 (± 4) N across conditions; and (c) the amount of air remaining over time varied between the clothing assemblies ($p = .001$; Figure 3). For buoyancy measurement 2, these values averaged, irrespective of having rested or swum: W 14 (± 1) N, AS/S 10 (± 2) N, and S 6 (± 1) N and did not differ between resting and swimming manipulations ($p > .05$; Figure 3). With the exception of the control and summer clothing conditions (no difference observed; see Table 2), the buoyancy was always significantly lower in the second buoyancy measurement than the first, irrespective of whether the participants rested using floating or swam. A significant amount of residual buoyancy still remained in all clothing conditions irrespective of having floated or swum in comparison with the control condition ($p = 0.02$); this averaged 10 (± 4) N across clothing conditions. Table 2 provides details of mean (± *SD*) positive buoyancy in each clothing condition before and after submersion and Figure 2 shows this buoyancy adjusted against the buoyancy evident in the control condition.

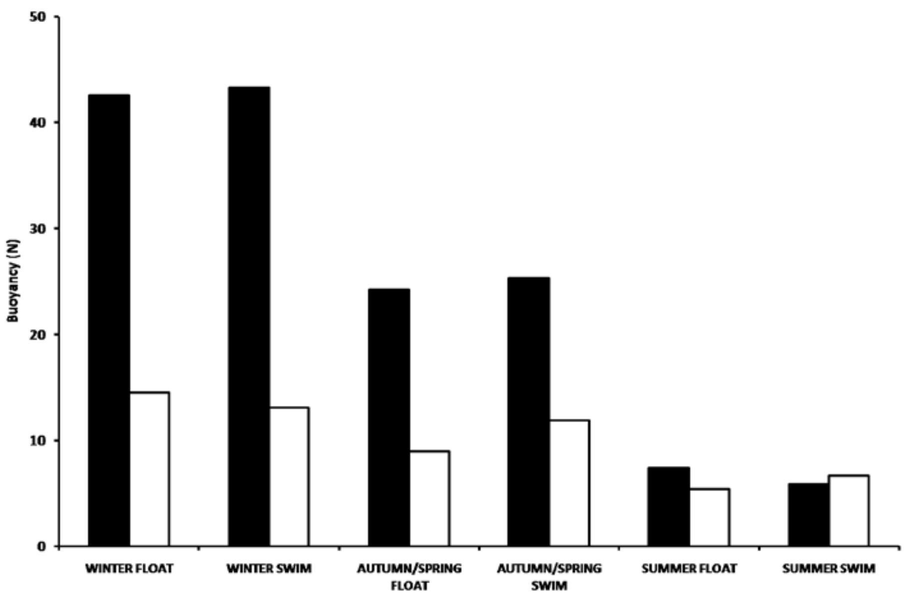

Figure 2 — Mean buoyancy (N) adjusted against the buoyancy evident in the control condition in all participants from study 1 before (black bars) and after (white bars) swimming or floating ($n = 24$).

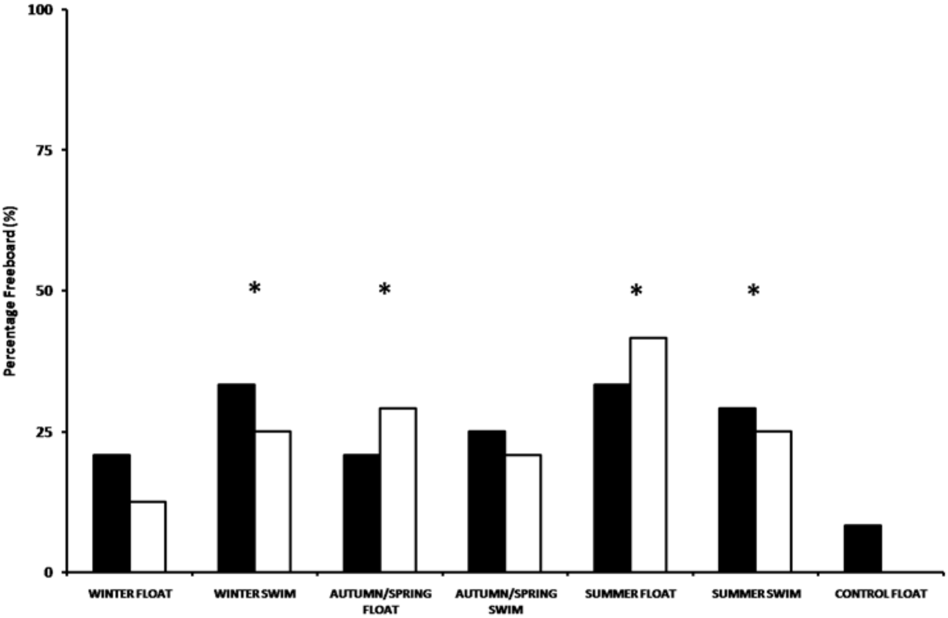

Figure 3 — Mean percentage freeboard achieved in each clothing condition in adult males tested in study 1 before (black bars) and after (white bars) swimming or floating (n = 12); * denotes significantly different to control condition.

Table 2 Positive Buoyancy (Newtons, N) Measured During 20 s Submersion Before and After Floating or Swimming

	WF (N)	WS (N)	A/SF (N)	A/SS (N)	SF (N)	SS (N)	CF (N)
Subm 1 (n = 24)	*104 (12)^{a,b,c}	*105 (12)^{a,b,c}	*86 (14)^{b,c}	*87 (12)^{b,c}	69 (11)^{c}	67 (11)^{c}	61 (11)
Subm 2 (n = 24)	76 (12)^{b,c}	74 (21)^{b,c}	*70* (12)^{b,c}	73 (11)^{b,c}	67 (8)	68 (10)	61 (11)
Males Subm 1 (n = 12)	*99 (8)^{a,b,c}	*100 (6)^{a,b,c}	*80 (9)^{b,c}	*84 (8)^{b,c}	62 (8)^{c}	63 (7)^{c}	57 (6)
Males Subm 2 (n = 12)	68 (8)^{c}	64 (24)	65 (11)^{c}	69 (11)^{c}	60 (9)	62 (8)	58 (7)
Females Subm 1 (n = 12)	*109 (15)^{a,b,c}	*109 (16)^{a,b,c}	*91 (16)^{b,c}	*90 (15)^{b,c}	76 (9)^{c}	71 (13)^{c}	65 (13)
Females Subm 2 (n = 12)	84 (12)^{a,b,c}	85 (8)^{a,b,c}	76 (11)^{c}	77 (10)^{c}	74 (8)^{c}	74 (8)^{c}	65 (14)

*denotes significant difference between submersion 1 and 2 within condition, a = greater than the A/S condition, b = greater than S condition, and c = greater than the CF condition.

Overall, females were significantly more buoyant than were males ($p = 0.001$), but the statistical analysis revealed no significant male and female interactions between clothing assembly, condition, and across time (submersion 1 vs. submersion 2; see Table 2).

Freeboard

The freeboard data partially supported the observations seen in the buoyancy data where (a) the amount of air (buoyancy) trapped underneath the layers of clothing after submersion enabled the participants to achieve freeboard more often ($p = 0.001$), (b) the freeboard capability reduced significantly over time ($p = .041$), but (c) the freeboard capability did not vary in accordance with the buoyancy noted in each clothing assembly ($p = 0.11$). The freeboard characteristics also did not differ between floating and swimming manipulations ($p = 0.11$).

There were significant effects associated with gender where females achieved freeboard significantly more often ($p = 0.001$) than did males. This effect was evident in each clothing condition where, with the exception of the control condition on initial immersion ($p = 0.275$), females achieved freeboard significantly more often ($p = 0.001$) than did males. The percentage freeboard achieved in each clothing condition is displayed in males and females in Figures 3 and 4, respectively.

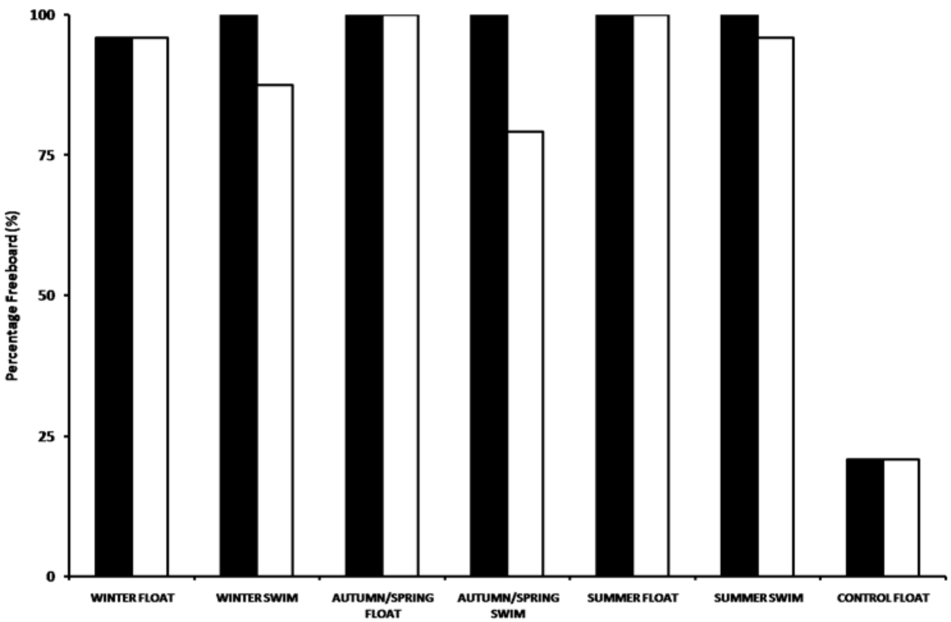

Figure 4 — Mean percentage freeboard achieved in each clothing condition in adult females tested in study 1 before (black bars) and after (white bars) swimming or floating ($n = 12$).

Irrespective of the clothing condition, experimental condition (floating or swimming) or gender, the participants achieved freeboard (i.e., the airway remained clear of the water) on 56 (19)% of occasions just following the first buoyancy measurement and 52 (± 20)% of occasions just before the second buoyancy measurement (n = 24). Males floated on 24 (± 9)% of occasions just after the first buoyancy measurement and 22 (± 13)% of occasions just before the second buoyancy measurement (n = 12). Females floated on 88 (± 30)% of occasions just after the first buoyancy measurement and 83 (±28)% of occasions just before the second buoyancy measurement (n = 12). In all cases, the freeboard statistic was significantly higher in all clothing conditions in females compared with the control condition (p = 0.001), but there were no differences between any of the clothing conditions (p = 0.58). In males, differences were evident between clothing conditions and the control (p = 0.02), but these differences did not alter as a consequence of swimming compared with floating (p = 0.488). With the exception of WF and AS/S all other conditions were different from the control. The freeboard statistics for males and females are displayed in Figures 3 and 4, respectively.

Correlational Data

In the winter clothing assembly, the initial freeboard value (i.e., just after the first buoyancy measurement) was significantly correlated with the first buoyancy measurement (p = 0.048, r = 0.407), the sum of skinfolds (p = 0.001, r = 0.738), the body fat percentage (p = 0.001, r = 0.859), and the vital capacity (p = 0.001, r = 0.647). Relationships were also found between the freeboard value generated just before the second buoyancy measurement and the second buoyancy measurement (p = 0.001, r = 0.622), the sum of skinfolds (p = 0.001, r = 0.748), the body fat percentage (p = 0.001, r = 0.879), and the vital capacity (p = 0.001, r = 0.649). These relationships were not as strong in the control condition as they were when clothing was worn. The initial freeboard value was correlated with buoyancy measurement (p = 0.046, r = 0.411), sum of skinfolds (p = 0.002, r = 0.595), body fat percentage (p = 0.002, r = 0.595), and vital capacity (p = 0.034, r = 0.435).

Study 2

Participants

The study was approved in advance of data collection by the University of Portsmouth Biosciences Research Ethics Committee. All participants provided written and informed consent to participate. Where participants were under the age of 18 years, written assent for participation was given by their parent or guardian. All participants were screened to ensure they were fit to complete the study and provided health history information. The physical characteristics of participants in study 2 are reported in Table 3.

Experimental Design

Participants visited a local swimming pool on one occasion where they completed two immersions into warm water (29.5 °C). Both immersions took place while wearing the winter clothing assembly with a similar CLO to that used in study 1.

Table 3 Mean (*SD*) Participant Characteristics for Children and Adolescents Who Completed Study 2

	Age (years)	Height (m)	Mass (kg)	Skinfold (mm)	Body Fat (%)
Overall (*n = 29)*	12 (3)	1.53 (0.2)	48.7 (15.8)	36.9 (19.4)	20.9 (6.4)
Junior Males (*n*=16)	13 (3)	1.55 (0.2)	51.6 (17.2)	33.1 (17.0)	18.1 (5.3)
Junior Females (*n*=13)	12 (2)	1.51 (0.1)	45.1 (14.0)	41.6 (21.7)	24.3 (6.2)

Freeboard was measured subjectively and quantitatively at the start and end of each immersion (see Figure 1). The two experimental manipulations were a "float only" (rest) condition and one condition where freeboard measurement was followed by up to 25 m of submaximal breast stroke swimming; the tests ended with a further freeboard measurement.

Experimental Procedure

The timing of all data points (i.e., initial freeboard measurement, second freeboard measurement) was matched to those noted in the first condition (winter clothing assembly and swimming). Each test lasted approximately two minutes. The participants dressed in winter clothing assembly and lowered themselves on to the second step of the pool's entry steps while holding on to the hand rail. At this time only their feet were immersed. Following a countdown, the participants fell backward into the water with arms outstretched and to the side of the body. Following water entry, the participants lay still in the water while an objective (see measurements section) and subjective assessment (experimenter observation) was made of the freeboard. Depending upon the experimental manipulation, the participants then either swam a maximum of 25 m (swim manipulation) or remained still, paddling as little as possible to remain afloat (float manipulation). If the participants were unable to swim 25 m, they stopped, lay on their back, and freeboard was measured before exiting the pool. The total distance covered was recorded. The test ended following the second freeboard measurement.

The participants then undressed to a bathing costume, dried with a towel, and redressed in dry clothes in preparation for the floating experimental condition. Freeboard measurements before and after the float condition were compared with the swim condition used to indicate the extent of any buoyancy retained in the clothing. Body composition was also measured (see below) either before or following the immersion tests.

The winter clothing assembly corresponded to that used in the laboratory tests (study 1) and was based on the insulation required to keep an average individual warm in winter conditions. The participants were asked to bring two sets of their own clothing to ensure a good fit of the garments. The experimenters provided the waterproof jacket sized to fit.

Measurements

Quantitative measurements of the practical significance of any inherent buoyancy (freeboard) were made on two occasions during each test. The quantitative measurement was made using a parallax measuring device (see Figure 5), deployed by a safety swimmer who was in the water adjacent to the participants throughout all tests. The freeboard measuring device was a perspex cylinder mounted on a swim float, with gradations marked at 0.5cm intervals on opposite sides. The zero baseline was set at the water level. The safety swimmer measured the height of the lowest part of the mouth above the waterline by fixating upon the mouth and aligning the measurement scales situated on the parallax device on either side of the perspex cylinder. The value that corresponded to the point where the measurement scales crossed on either side of the cylinder was recorded by an experimenter at the poolside. On one occasion, participants completed the same anthropometric profile as noted in study one with body composition calculated using an equation suitable for body fat estimation in children (Brook, 1971).

Means (± *SD*) for the objective freeboard data were calculated for the measurements generated before and after resting or swimming using both qualitative and quantitative data. Data were then compared using a repeated measures analysis of variance (ANOVA) for change in freeboard, both as a consequence of swimming compared with resting and between genders.

To gain an estimation of the physical effort required to swim the 25 m in comparison with floating, participants were asked to rate their required effort on a modified Borg (1982) scale where 1 corresponded to *low intensity exercise/easy* and 10 corresponded to a *maximal effort exercise/hard*. These data were statistically examined for differences using a paired samples *t* test.

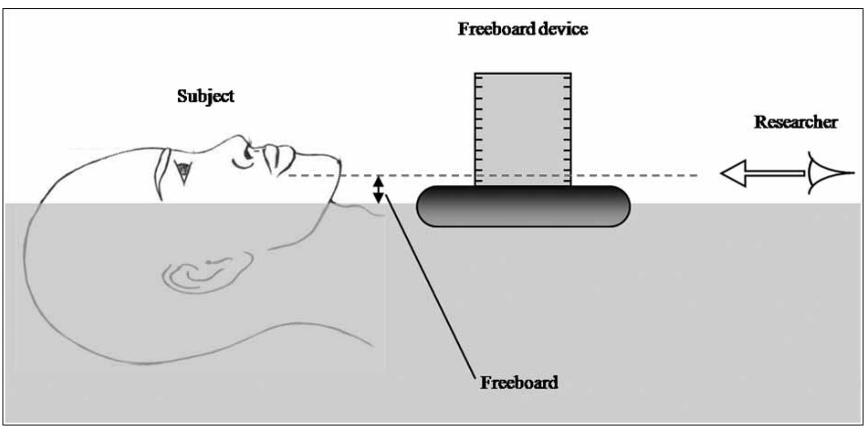

Figure 5 — Pictorial representation of how buoyancy was quantified using the parallax device in study 2.

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Swim Performance

The average (*SD*) distance swum by the participants was 24 (± 4) meters and was similar in males, 23 (± 5.3) m and females, 25 (± 0.0) m. The time taken to complete this distance averaged 69 (± 14) seconds and was again similar between males, 69 (± 15) s and females, 69 (± 12) s. The duration of the float condition was matched to the duration of the swim condition. The participants perceived that the effort required to swim was significantly greater, 6 (±2) out of 10, than that required to float, 3 (± 2) out of 10, for a similar period of time ($p = 0.001$).

Freeboard

When freeboard was directly quantified, the airway remained clear of the water on initial immersion by an average (*SD*) of 5.5 (± 3.0) cm ($n = 29$), a distance that was similar in males, 5.5 (± 3.4) cm and females, 5.4 (± 2.7) cm. The airway became significantly closer to the water over time ($p = 0.001$), but this distance was not influenced by whether the participant swam or remained still (floated $p = 0.992$). There was no difference in the decrease in the freeboard measurement between males and females ($p = 0.849$); freeboard measurement 2 averaged 3.0 (± 1.7) cm ($n = 29$) and was 3.4 (± 1.7) cm in males ($n = 16$) and 2.7 (±1.7) cm in females ($n=13$).

The freeboard statistics and effects were the same as noted above. Irrespective of clothing condition, experiment condition, and gender, the participants floated (i.e., the airway remained clear of the water) on 94 (± 21)% of occasions just following entry to the water and 77 (± 30)% of occasions at the end of the experiment ($n = 29$). Males floated on 92 (±27)% of occasions just after entering the water and 75 (± 32)% of occasions at the end of the experiment ($n = 16$). Females floated on 96 (± 13)% of occasions just after entering the water and 79 (±29)% of occasions at the end of the experiment ($n = 13$).

General Discussion

Study 1 examined the extent to which buoyancy was provided by air trapped between clothing layers on immersion and whether staying still (floating) enabled more air to remain trapped between clothing layers in the early minutes of immersion. The data suggest that a significant amount of buoyancy, over and above that seen when unclothed (control), was present on initial immersion; the experimental hypothesis (a) is therefore accepted. Indeed, up to an average of 45 N of buoyancy (similar to that provided by an entry level buoyancy aid) was apparent in the winter clothing assembly, with this clothing assembly providing the greatest amount of buoyancy in the present tests. As the clothing layers were reduced, the amount of inherent buoyancy was also significantly reduced to 25 N and 7 N for autumn/spring and summer, respectively. The experimental hypothesis (b) is again accepted. Buoyancy was reduced to a similar value within each clothing condition irrespective of whether the participants swam or floated after the first buoyancy measurement. Experimental hypothesis (c) is therefore rejected. During the second buoyancy measurement, clothing provided 5–14 N more buoyancy than that seen in the control condition, with the winter clothing assembly again providing the most buoyancy at this time.

Despite the increased buoyancy with clothing layers, the participants were only able to lie still with their airway clear of the water (freeboard) on half of the occasions. Those participants who were initially able to float were still able to do so even if they had swum for two minutes. This, in part, can be attributed to gender differences. There were clear differences in measured buoyancy and freeboard between adult males and females, confirming that physical characteristics, such as percentage body fat (Table 1), play a role in determining the ability to remain afloat. In study 2, the average estimated body fat percentage of boys undertaking the current studies was about four percent higher than that of the adult males (Table 3). This is similar to the difference seen in anthropometric studies (Guo, Chumlea, Roche, & Siervogel, 1998). Using the data of Barlett et al. (1991), based on U.S. citizens, it is possible to estimate the ratio of fat mass to fat free mass for children and adults of corresponding age to those in the current study. Given the buoyancy characteristics of human fat and fat-free tissue, the higher this ratio, the more likely it is that an individual will be able to float. In adult females and children, this ratio is reported as being between 0.29 and 0.30 in boys and girls aged 11–13 years old and closer to 0.35 in adult females aged 19–22 years old. This is reported as being lower in adult males who have a ratio closer to 0.24 (19–22 years old; Barlett et al., 1991), whereas the adult males tested in study 1 have a ratio of closer to 0.17; this helps to explain the relative difficulty this group have in achieving freeboard.

The data from study 2 suggest that children with an average age of 12 years of age who wore typical winter clothing were able to float on entry to water and keep their airway clear of the water with only minimal paddling. The ability to float was relatively unaffected by a short period of swimming in comparison with remaining still, which suggested that any inherent buoyancy created by trapped air between clothing layers diminishes by a small amount with time, irrespective of body movement. These data agree with the observations made on adults in study 1.

The results obtained from children and adults were not identical. From the tests conducted, the vast majority of children were able to float irrespective of gender; this finding corresponded with that seen in adult females, with a smaller percentage of adult males being able to float without paddling. The differences in the responses seen between children and adult males may in part be due to the methodological differences between studies 1 and 2 (i.e., no prior buoyancy quantification in study 2 before freeboard measurement). Alternatively, it could be due to the similarities and differences in the anthropometric characteristics of children and adult females and males, and the possibility that the amount of air trapped in the clothing assembly of children is relatively greater in relation to body mass due to the higher surface area to mass ratio of children. This combined with buoyant footwear (i.e., trainers) may have been sufficient to enable flotation in most children.

The volume of air in the lungs (Pendergast, di Prampero, Craig, Wilson, & Rennie, 1977) and the temperature, salinity, and viscosity of water in which the immersion takes place will also influence float capability. In addition to these factors, our data suggest that the type of clothing worn will also influence the ability to retain buoyancy. The permeability of the surface clothing layer, which was waterproof in the present tests, appears to be the main determinant of the amount of buoyancy provided and the rate at which it dissipates. When the waterproof layer was not worn, the initial buoyancy was reduced to ~7 N, a value that we primarily attribute to the wearing of trainers which were partly comprised of foam. However, even this minor addition to buoyancy enabled the female participants to "float freely" on approximately 95% of occasions; this percentage fell to ~25% when the trainers were removed in the control condition (Figure 4).

It is also possible that during an actual accidental immersion, more buoyancy would be retained in clothing than was established in the present tests. This is because the measurement of buoyancy by underwater weighing may, itself, have reduced buoyancy due to hydrostatic compression of the clothing. While this will occur on any immersion, experimental or accidental, it is unlikely that an immersion victim would be held underwater for a period of 20 s necessary in the present experiments to determine underwater weight in a scientifically valid and reproducible way. It is interesting to note that the buoyancy data in the first 5 s of submersion in winter clothing condition was 59 (± 13) N and subsided to 39 (±13) N in the final 5 s of submersion (data adjusted against the control condition). Despite the extended period of submersion the buoyancy data showed a significant relationship with the freeboard data in both the control and winter clothing conditions. During an accidental immersion, it is possible that the victim's head would be forced below the level of the water. In such a situation, air trapped in the hood of the clothing could assist the victim in returning to the surface of the water and help keep the airway clear of water.

We concluded that a significant amount of air is trapped by clothing on immersion in water, and the volume of this air is primarily dependent on the permeability of the surface clothing layer. This buoyancy is reduced over the initial minutes of immersion, irrespective of whether an individual swims or floats, but for up to at least two minutes, buoyancy remains higher than that seen without clothing. Therefore, the wearing of clothing may assist buoyancy in certain real life scenarios where accidental immersion occurs. Further investigations may be required to cover other aspects of the immersion scenario not covered in this investigation (e.g., effects of water temperature, salinity, viscosity, and currents) to provide further evidence for the value of this survival mechanism. Based on the present data, any inherent buoyancy may be of greater assistance to children and adult females who are better able to float than adult males. Consistent with observations from the cold immersion literature (Golden et al., 1986), which suggest that cold shock can cause swim failure during the initial minutes of immersion, our data support a policy of "float first" for the initial minutes of accidental immersion in cold water, and we advocate that this survival behavior should be taught to children in conjunction with learning to swim. The effort required to swim even a short distance in warm water is significantly increased by wearing clothing, and the fatigue associated with clothed swimming is likely to be exacerbated in cold water (Tipton et al., 1999). Therefore, the behavioral advice after the early minutes of cold water immersion may be to remove clothing layers before attempting to swim to safety; the evidence for this approach has yet to be established. The policy of "float first" does not reduce the importance of learning to swim or of becoming confident in the water (i.e., developing water competence).

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