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Human Kinetics
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Inertial Measurement Units (IMUs) in Drowning Prevention: An Exploratory Study

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The use of inertial measurement unit (IMUs) sensors in competitive swimming movement analysis has become increasingly popular but has not been applied to measuring water competencies related to drowning prevention. This study explored the potential use of IMU sensors in three simulated water competency activities in a pool environment. Participants were a subset ($n = 12$) of a cohort of students ($n = 37$) taking part in the Can You Swim in Clothes? project. Participants undertook a swim for speed test over 25 m, a distance swim of 5-min duration, and a flotation test, also for 5 min, wearing swimwear and again in lightweight street clothing while wearing an IMU to measure leg acceleration forces. Results showed that clothing impeded swimming sprint speed and distance but not flotation. Authors suggest further research with regard to IMU placement, appropriate survival activities, and measurement protocols and recommend the need for expanded future IMU use.

Keywords: water competence, drowning prevention, water safety, inertia measurement unit (IMU)

The use of accelerometry is an increasingly popular method to estimate the metabolic rate of free-moving animals. Laboratory studies of a wide variety of mammals and birds of differing sizes exercising in respiration chambers show highly linear correlations between oxygen consumption and dynamic body acceleration (DBA; Halsey, Green, Wilson, & Frappell, 2009; Halsey, Shepard, et al., 2009). Recent competitive swimming studies have used inertial measurement units (IMUs) to provide precise and accurate information on propulsion and stroke effectiveness

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(Dadashi, Millet, & Aminian, 2013; De Magalhaes, Vannozzi, Gatta, & Fantozzi, 2015). IMUs are electronic devices that measure and record swimmer's velocity, limb positional orientation, and gravitational forces using a combination of accelerometers, gyroscopes, and magnetometers. To our knowledge, IMU use to analyze human performance in simulated drowning prevention tasks has received no research attention. The nature of water competency performances includes, but is not confined to, swimming locomotion tasks, and their roles in drowning prevention has received recent research attention (e.g., Kjendlie et al., 2013; Moran, 2014a, 2014b, 2015; Moran et al., 2012). Precise quantitative analysis of swimming locomotion in a drowning prevention mode using microchip computer technology has not been the subject of scrutiny. It occurred to the authors that if recent advances in microtechnology can facilitate evaluation of competitive swimming stroke efficiency, then it ought to be equally able to assess the ease with which a person can survive (or perish) in a drowning situation. It is the purpose of this article to present some initial exploratory results from the use of IMUs in several simulated swimming and water competency activities.

Video analysis has traditionally been used to obtain kinematic biomechanical data on swimming stroke technique, efficiency, and qualitative correction for competition purposes. The availability of low-cost waterproof video cameras has facilitated their use by coaches to assess stroke efficiency among elite swimmers (Callaway, Cobb, & Jones, 2009). The difficulties associated with any three-dimensional analysis of human movement requiring multicamera recording on land are compounded in an often turbulent fluid medium. Difficulties in coping with water turbulence, synchronizing of underwater cameras, variations in tracking procedures, and intensive data processing have limited the availability of information to coaches and swimmers alike (Dadashi et al., 2013; De Magalhaes et al., 2015). The first study using IMUs in swimming was carried out by Ohgi, Yasumura, Ichikawa, and Miyaji (2000). They investigated the relationship between wrist acceleration and blood lactate for the purpose of evaluating fatigue during intense training. Further studies using IMUs have identified different propulsive sweep phases in front crawl and breaststroke (Ohgi, 2002; Ohgi, & Ichikawa, 2002; Ohgi, Ichikawa, Homma, & Miyaji, 2003). Others have analyzed all four competitive styles using IMUs strapped to the wrist and/or upper back (Davey, Anderson, & James, 2008; Hou, 2012; Slawson et al., 2008). Stamm and colleagues investigated the use of sensors attached to the lower back to determine whether velocity information can be derived from acceleration data in freestyle swimming for a recreational swimmer (Stamm, James, & Thiel, 2013) and elite swimmers (Stamm, Thiel, Burkett, & James, 2011). Acceleration data obtained from a single IMU placed on the sacrum of 30 elite and recreational swimmers suggested that IMU measurement was an effective evaluator of swimming performance (Dadashi, Crettenand, Millet, & Aminian, 2012).

Two recent systematic reviews on wearable inertial sensors in swimming motion analysis have identified more studies on all four competitive strokes (Dadashi et al., 2013; De Magalhaes et al., 2015). De Magalhaes and colleagues (2015) reviewed the use of a variety of sensors (including 2-D/3-D accelerometers and/or 3D/1D gyroscopes); differing sites used (including wrist, chest, upper and lower back, dominant kicking leg); differing strokes used; differing experimental designs (including single-subject and group studies, competitive, Paralympic, recreational, and occasional swimmers). They concluded that inertial sensors were a reliable measurement tool for performance assessment in the aquatic environment, could be easily incorporated into coaching feedback mechanisms, and increased the amount of information available throughout sustained activity, thereby allowing evaluation of fatigue effect on stroke proficiency (De Magalhaes et al., 2015).

In the drowning prevention domain, several studies associated with the Can You Swim? project have identified and tested water competencies (such as swimming speed, swimming endurance, and flotation) that are proposed to be critical to preventing drowning (Kjendlie et al., 2013; Moran 2014a, 2014b, 2015; Moran et al., 2012). Water competence is defined here as the sum of all personal aquatic movements that help prevent drowning, as well as the associated water safety knowledge, attitudes, judgments, and behaviors that facilitate safety in, on, and around water. In an open-water situation (where most drowning occurs), swimming competence is likely to be compromised by many impediments such as cold, rough water, and clothing. Exploration of swimming competency from a drowning prevention perspective would thus benefit from studying challenges that simulated survival conditions provide rather than simply assessing swimming performance.

Recent studies have suggested that survival swimming competency is compromised in rough water (Kjendlie et al., 2013) and when wearing clothing (Amtmann, Harris, Spath, & Todd, 2012; Choi, Kurokawa, Ebisu, Kikkawa, Shiokawa, & Yamasaki, 2000; Moran, 2014a, 2015). Studies have also reported that other water competencies such as survival floating (Kjendlie et al., 2013; Moran, 2014a, 2015) and exiting the water (Moran 2014b) are also adversely affected by factors such as rough water and clothing. The opportunity to explore the use of IMUs in simulated drowning survival came about in relation to the Can You Swim in Clothes? project's being conducted at the same time as the local release of a new IMU product specifically designed for use in water (further information is available at www.imeasureu.com).

On the basis of the reported literature and systematic reviews, the purposes of the current study were as follows:

- To explore the use of IMU sensors in simulated survival swimming activities in a pool environment.
- To develop a set of protocols to test water competencies commonly associated with drowning prevention.
- To make recommendations to guide future use of microchip technology in drowning prevention studies.

Method

The study design chosen for this exploratory phase of the Can You Swim in Clothes? project using IMU technology was a within-subject experimental design where the participants served as their own controls. Testing took place in an outdoor 25-m × 12-m, six-lane pool (water temperature 21 °C). Appropriate lifeguard supervision and safety equipment were available at all times. Ethics clearance for the study was obtained from the University of Auckland Human Participants Ethics Committee as part of the Can You Swim in Clothes? project (Case No. 010667).

Participants and Procedures

Participants were a subset (*n* = 12) of a cohort of students (*n* = 37) taking part in the Can You Swim in Clothes? project. All students were enrolled in a physical education undergraduate degree program that included an aquatics education course as part of their professional teacher education degree. The participants were volunteers with a proven swimming capacity who agreed to take part in extracurricular sessions outside their normal timetabled classes. Individualized testing of water competencies was completed over 2 weeks during the summer term (March–April 2014).

For each individual, the testing required approximately 20 min of in-water work in 2 successive weeks with each session at the same time each week. The week-long interval between testing was intended to minimize both fatigue and learning effects. The tests were completed at the same time of day each week so as to minimize the possible effects of the circadian rhythm (Alberty, Sidney, Pelayo, & Toussaint, 2009). A total of four sessions (6 participants per 2-hr session) were required to test all 12 participants twice, once in swimwear and once in clothing. The clothing worn was standardized and included wearing a T-shirt, a long-sleeved sweatshirt, long legged trousers/track pants, and swimwear underneath the clothing as reported in the previously published clothing study (Moran, 2014a, 2015). Footwear and outer clothing were not included at this exploratory stage because of the possible effects the variability of the attire might have on performance (such as buoyancy of shoes and air trapped in, and increased drag on, outer clothing) as previously reported by Barwood and colleagues (Barwood, Bates, Long, & Tipton, 2011).

Research Instruments

The IMU used in this study was based on the chip used in the I Measure U proprietary products (I Measure U, Auckland, New Zealand, www.imeasureu.com). The IMU had a 9-axis chip that measured acceleration in three dimensions, angular velocity (from the gyroscope) in three dimensions, and the absolute magnetic field with respect to magnetic north in three dimensions (magnetometer). The sensor was hermetically sealed and encased in epoxy resin with dimensions of 33 mm × 21 mm × 13 mm (Figure 1), weighing approximately 12 g and charged via wireless power transfer. The data logging rate was set to 100 Hz. The data reported from the IMU included time (in seconds), acceleration (in m/s/s), and gyroscope (in radians/degrees per second). The IMU was attached to the distal tibia of the left lower leg, 2 cm above the medial malleolus using 38-mm surgical tape (see Figure 1). The reasons for locating the IMU on the distal and lateral

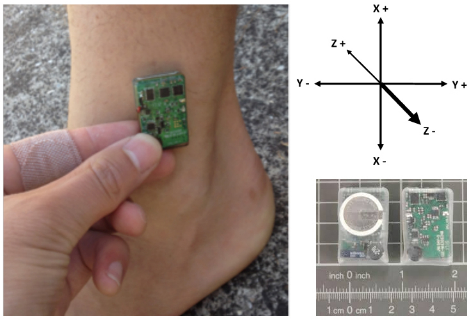

Figure 1 — Location of inertial measurement unit (IMU) placement on lower leg and orientation of IMU axes.

ankle were that it minimized drag force (Bächlin & Tröster, 2012), caused the least interference with the survival activities, and did not limit range of motion in either swimming or floating activity, irrespective of technique employed.

Data Gathering

The aquatic competencies considered critical to drowning survival were speed swimming, endurance swimming, and flotation. Protocols for the tests were based on the procedures developed for the original Can You Swim? project (Moran et al., 2012) and the subsequent Can You Swim in Waves? project (Kjendlie et al., 2013) and were modified to suit the wearing of clothing.

The speed swim consisted of a 25-m maximum-speed sprint that started with a push off the wall at the deep end of the pool. Participants were told to imagine that they had to swim as fast as they could to safety a short distance away as quickly as possible. The second task comprised of a 5-min endurance swim where the participants were instructed to swim without touching the sides or bottom of the pool as strenuously as they could but while making sure they completed the time limit. Participants were told they could change strokes but must remember the pattern of the swim and repeat that pattern during the endurance test in clothes. The third task was a 5-min stationary float in the deep end of pool (water depth was 2 m). Swimming was not permitted, but either horizontal or vertical flotation with minimal arm and leg movements was permitted to accommodate the varying body composition of participants.

All the tasks were completed in succession with 1 min rest between each activity. The accelerometer data were recorded throughout the duration of the 20 min with participants required not to move their lower left leg during the in-water resting phase to exclude incidental activity from the continuous recording. The data files were downloaded at the poolside after each 2-hr session (6 participants) and included time-stamped raw data for accelerations, angular velocities, and magnetometer all in three axes, as well as a quaternion that defined the absolute orientation of the sensor at each particular time stamp. The testing was also recorded on video, and a log of real-time activity was kept to facilitate annotation of the accelerometer data and remove unwanted activity.

Data Analysis

Data were stored as a .csv file and imported into R (R Core Team, 2015). The data corresponding to defined swimming activities and individuals were matched to the raw accelerometer output via graphical visualization of the acceleration data and notes on the times individual participants carried out activities. Next, the x, y, and z acceleration values (recorded as a plus or minus value depending on which side of the axis was being accelerated) were smoothed using a running mean across 500 data points (equivalent to 5 s) to quantify the static acceleration component of the total acceleration value (Wilson et al., 2006). The static acceleration value was then subtracted from each observation to derive the DBA, which represents only the dynamic component of movement and removed the effect of gravitational acceleration (Gleiss, Wilson, & Shepard, 2011). The absolute value of DBA was then summed across axes to derive the overall dynamic body acceleration (ODBA; Wilson et al., 2006), which is expressed in units of *g*, where 1 *g* is equivalent to gravitational acceleration of 9.81 m s^{-2}. The ODBA was chosen over the vector of the DBA as the former is a better proxy for energy expenditure when the accelerometer placement is standardized between subjects (Qasem et al., 2012).

Results

The participants were $N = 12$ young adults (ranging from 20–25 years of age), half were female ($n = 6$), and most (92%) considered themselves to be very good (25%) or good swimmers (67%). Most (83%) estimated that they could swim 200 m or more; one quarter (25%) thought they could swim 400 m or more. Most (58%) were confident that they could swim the estimated distance in open water, although more women than men (83% vs. 8%) were anxious about swimming in open water, as previously reported (Moran, 2014a).

Figure 2 illustrates the leg acceleration of one participant wearing clothes throughout the duration of the test. The plots show the relationship between the acceleration recorded on the *x*, *y*, and *z* axes for the three competencies tested from the point when the participant entered the water until the time of exiting, covering approximately 14 min per individual.

Table 1 reports the comparative performance of the 12 participants in the three water competencies when the tasks were performed in swimwear and when wearing lightweight street clothing. Table 2 reports performance in the same tasks but compares the leg acceleration (OBDA) of the participants when wearing swimwear and clothing.

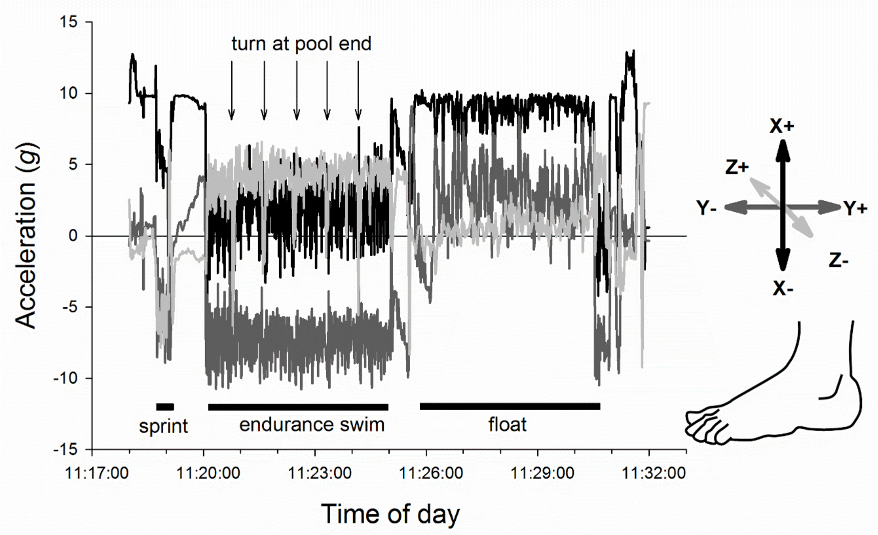

Figure 2 — Leg acceleration (in *g*) in *x*, *y*, and *z* axes during in-water testing.

Table 1 Comparison of Swimming and Floating Proficiency in Swimwear Versus Clothes

	25-m sprint swim (seconds)				5-min endurance swim (m)				5-min floating (aptitude score 1–10)			
Participant	Swimwear	Clothes	Difference	% difference	Swimwear	Clothes	Difference	% difference	Swimwear	Clothes	Difference	% difference
1	17.9	23.8	5.9	25%	175	135	–40	–30%	6	5	–1	–10%
2	18.4	28.7	10.3	36%	190	140	–50	–26%	7	5	–2	–20%
3	21.2	31.6	10.4	33%	150	120	–30	–20%	9	9	0	0
4	20.4	28.5	8.1	28%	225	170	–55	–24%	9	9	0	0
5	22.4	39.7	17.3	44%	150	115	–35	–24%	9	9	0	0
6	17.3	24.5	7.2	29%	300	200	–100	–33%	9	9	0	0
7	16.2	23	6.8	30%	256	170	–86	–34%	7	6	–1	–10%
8	17.8	27.9	10.1	36%	200	130	–70	–35%	7	7	0	0
9	15.6	21.6	6	28%	260	188	–72	–28%	9	8	–1	–10%
10	19	29	10	35%	212	170	–40	–19%	9	9	0	0
11	20.5	30.8	10.3	33%	210	145	–65	–31%	8	8	0	0
12	15.4	24.8	9.4	38%	270	175	–95	–35%	6	6	0	0
Mean	18.5	27.8	9.3	33%	216.5	154.8	–61.5	–28%	7.9	7.5	–0.4	–4%

Note. Units are *g*.

Table 2 Comparison of Leg Acceleration During Swimming and Floating Tests in Swimwear Versus Clothes

	25-m sprint swim				5-min endurance swim				5-min floating			
Participant	Swimwear	Clothes	Difference	% difference	Swimwear	Clothes	Difference	% difference	Swimwear	Clothes	Difference	% difference
1	2.9	1.6	–1.3	–45%	3.6	3.9	0.3	7%	5.1	3.9	–1.2	–23%
2	6.1	4.6	–1.5	–24%	3.7	3.1	–0.6	–17%	1.6	2.4	0.8	51%
3	4.4	4.4	0.0	0%	3.2	4.2	1.1	33%	2.6	1.9	–0.8	–29%
4	5.3	2.6	–2.7	–50%	5.6	6.2	0.6	11%	3.7	2.9	–0.7	–19%
5	1.7	3.9	2.1	125%	4.5	3.5	–1.0	–22%	3.8	2.2	–1.6	–41%
6	4.3	1.7	–2.6	–60%	4.2	4.9	0.7	17%	0.9	0.6	–0.3	–34%
7	3.0	3.3	0.3	10%	2.9	3.8	0.9	31%	1.5	1.5	–0.1	–4%
8	2.4	3.9	1.6	66%	4.1	3.4	–0.7	–18%	1.0	0.9	–0.2	–15%
9	7.4	3.5	–3.8	–52%	4.5	4.4	–0.1	–2%	1.3	1.0	–0.4	–29%
10	3.1	1.4	–1.7	–55%	4.8	4.3	–0.5	–10%	3.1	2.6	–0.6	–18%
11	2.8	1.7	–1.1	–38%	4.5	3.5	–1.1	–24%	3.3	3.4	0.2	5%
12	6.0	1.1	–4.8	–81%	3.3	4.0	0.7	22%	2.9	2.8	–0.1	–2%
Mean	4.1	2.8	–1.4	–20%	4.2	4.1	0.0	2%	2.6	2.2	–0.4	–13%
SD	1.7	1.2	2.0	16%	0.2	0.2	0.2	6%	0.4	0.2	0.2	7%

Note. Units are *g*.

Sprint Swimming

When swimming as fast as they could over 25 m, all participants were slower when wearing clothes (mean difference 33%).When the sprint was analyzed in terms of leg acceleration (ODBA), a wide range of acceleration values was evident even though a similar pattern of reduced proficiency was discernible (Table 2). Eight of the 12 participants showed reduced leg acceleration in clothes when sprint swimming (Table 2). A weak relationship ($R^2 = .23$) between leg acceleration and sprint proficiency in swimwear was observed (Figure 3A). No relationship ($R^2 = .10$) was found between leg acceleration and sprint proficiency when wearing clothes (Figure 2A). In addition, no consistency was found in participant leg acceleration force when sprint swimming irrespective of whether the swimmer was wearing swimwear or clothing ($R^2 = .01$, Figure 4A).

Endurance Swimming

When participants were clothed, the endurance swim of 5-min duration elicited a mean reduction of 28% in distance swum (Table 1). No consistent change in leg acceleration was found between participants when switching from swimwear to clothes (–2% ± 19% mean ± *SD*, Table 2). A narrower range of leg acceleration values was found in endurance swimming when compared with sprint swimming (Table 2). One participant (Participant 4) expended substantially higher leg force (5.6–6.2 *g*) compared with the others in swimwear and when clothed (3.1–4.9 *g*, Table 2, Figure 4B). A weak correlation was found between distance swum and leg acceleration for swimwear ($R^2 = .30$) and no correlation for distance swum when clothed ($R^2 = .04$, Figure 3B). No consistency was found in participant leg acceleration force expended and clothing type ($R^2 = .28$, Figure 4B).

Floating

Clothing did not cause a measurable decrease in floating competency (Table 1). No correlation was found between floating competency and leg acceleration for either swimwear ($R^2 = .01$) or clothes ($R^2 = .08$, Figure 3C). We observed a strong correlation between participant leg acceleration force expended and clothing type ($R^2 = .77$, Figure 4C), suggesting a consistency in leg use in floating technique with/without clothing.

Discussion

The purposes of this study were to explore the use of electronic sensors in simulated survival activities in a pool environment and determine whether IMU technology can enhance our understanding of drowning and its prevention. When the IMUs were applied during a test series of water competencies commonly associated with drowning prevention (speed swimming, endurance swimming, and floating) wearing either swimwear or clothing, the data reaffirmed findings of performance decrement in swimming activity when wearing clothes (Moran, 2014a, 2015) and offered some insights into how clothing state affects leg movements.

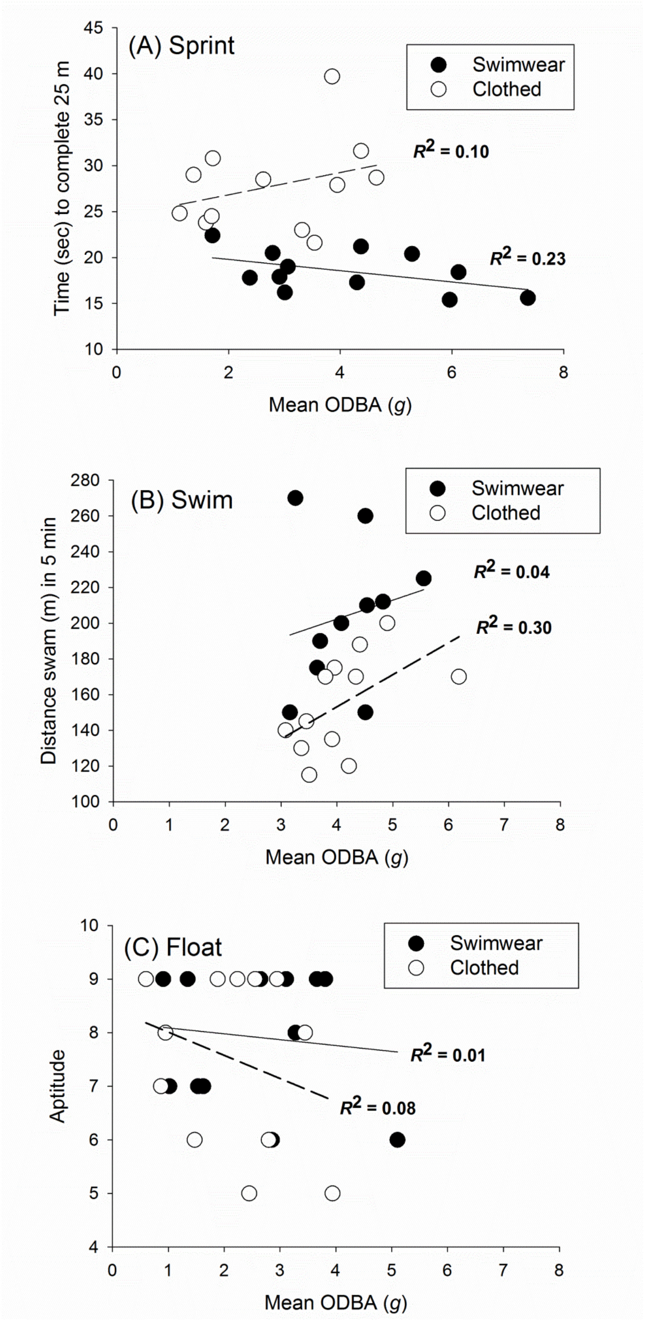

Figure 3 — Relationship between water competencies and leg acceleration (overall dynamic body acceleration; ODBA) for people in swimwear versus clothes.

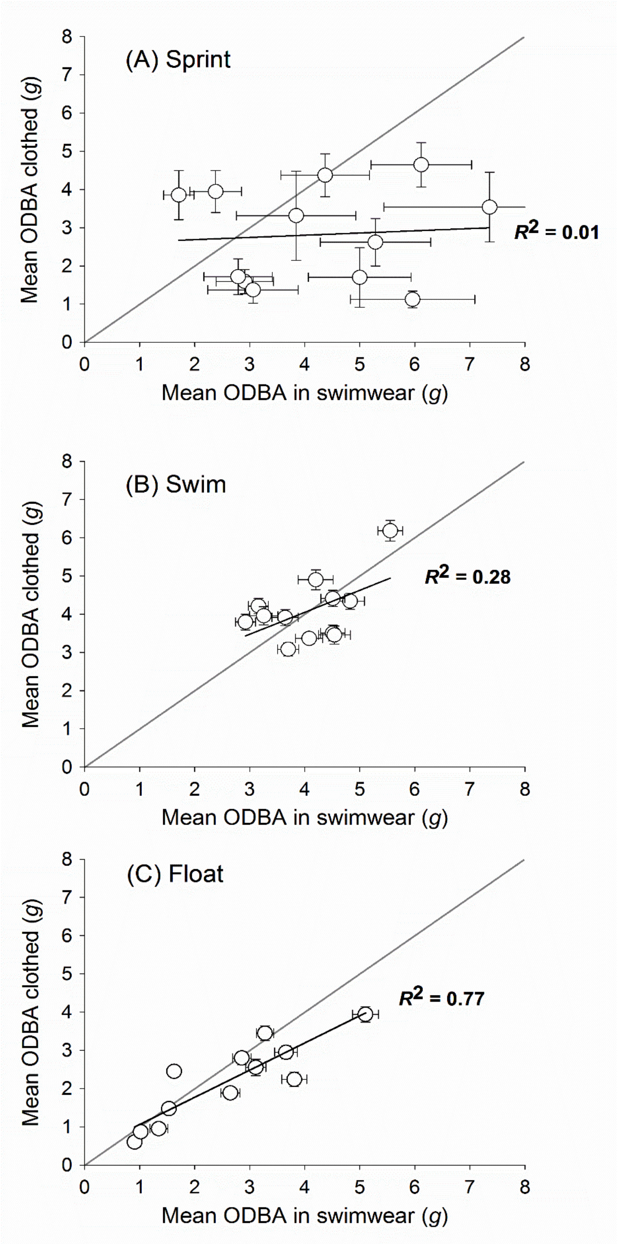

Figure 4 — Comparison of leg acceleration (A–C, mean ± *SD* overall dynamic body acceleration [ODBA] over activity duration) for water competencies in swimwear versus clothes.

To determine whether electronic sensors would confirm previously observed performance changes between swimwear and street clothing, we used IMUs to compare acceleration values between clothing states. Most aquatic IMU studies have kept the shape/surface of the individual consistent between treatments; therefore, any change in acceleration equals a change in energy expenditure. In this study, we did the opposite by measuring whether individuals elicited the same level of leg acceleration in clothing as they did in swimwear. On the basis of these results, we suggest that OBDA is an appropriate metric for use in analyzing changes in performance when wearing swimwear and clothing in the chosen swimming tasks. Under sprint swimming conditions, clothing generally dampened kicking effort and individuals exhibited considerable variation in swimming style compared with the same activity in swimwear. Wearing clothing during the endurance swim did not have a measurable effect on leg acceleration, and the current study reaffirmed that clothing does not appear to change floating competency, which confirmed what was previously reported (Moran, 2014a).

The positioning of the IMU for use in testing drowning prevention skills raised some interesting challenges, not the least being that previous IMU use had been targeted to specific limb use and swimming stroke whereas this study of survival activity required a much broader view. Initial reasons for locating the IMU above the ankle of the nondominant leg were that it would cause the least drag and interference with the survival activities and did not limit free range of motion in either swimming or floating activity, irrespective of technique employed. While our choice of positioning appears justified, an important qualification to the value of the findings is that only leg acceleration was measured and leg acceleration is but one contributor to swimming and floating technique.

The results suggested that wearing clothes lowered locomotive efficiency in the endurance swim with no measurable change in leg acceleration. There are two ways to interpret this finding. The first is that the participants exerted the same amount of energy in their kick for both clothing types; the leg presumably traveled a similar distance in the water and generated the same propulsive force. The clothing increased the drag and the sole reason for the loss of distance competency when clothed was differences in drag forces. The second interpretation is that the clothing imposed a hydrodynamic burden, the participants experienced significant drag on their legs, and they needed to expend more energy to generate the same force. The loss of distance performance with clothing could therefore be a combination of reduced overall body hydrodynamic efficiency and physiological fatigue associated with additional exertion to maintain a baseline level of kick speed. One method to tease these factors apart (loss of performance due to fatigue vs. hydrodynamics) would be to measure physiological stress indicators such as heart rate, blood pressure, or blood lactate and correlate this with accelerometry data.

For sprinting in clothes, however, an upper bound on the amount of force used was evident, which suggested that even if you kick harder, you will not move a clothed leg as fast as it could move unhindered. To test the impact of clothing on leg kick alone, future studies may consider the use of kickboards to isolate the influence of changes in body position brought about by wearing clothes.

Given the importance of arm propulsion in swimming and body position in floating, it may be more useful in future studies to also attach IMUs on the wrist to measure changes in arm propulsion, and lower back lumbar region to measure changes to body position. The latter offers considerable promise in assessing the consequences of fatigue and the impact of clothing on the capacity of a drowning person to maintain an airway. It may well be that rather than the drag created by clothing's reducing force exertion, a change in swimming technique and distribution of effort to other limbs may be responsible for reduced competency and thereby increasing drowning risk. In future studies, multiple use of IMUs on wrist, lower leg, and lower trunk may provide a more comprehensive analysis than was possible in this exploratory single-site study.

A further consideration for future use of IMUs in drowning prevention studies is the specificity of the data to swimming and floating technique. In this present study, participants were given freedom to choose their preferred techniques, the only restriction being the repetition of the same stroke selection in each speed and endurance swim when in swimwear and then in clothing. While this may be more reflective of choices likely to be required in a real survival situation, it does not allow for data comparison between individuals and helps explain the wide variations in acceleration data reported in Table 2. To make comparisons in competency capacity among individuals that could inform water safety teaching and advice, in future studies researchers may want to compare changes in limb acceleration and body position during in-water and out-of-water arm recovery to shed light on the most effective stroke selection. Such findings would be valuable in reinforcing the importance of appropriate stroke selection in drowning prevention scenarios especially when wearing clothing, similar to previously reported (Moran, 2015).

Limitations

While the results of this exploratory study using microchip technology substantiate previous findings of decreased performance in simulated water competency activities, several limitations merit consideration when contemplating further use of IMUs in studies on drowning prevention. First, since the participants in this initial study were capable swimmers, their water competency and fitness levels were likely to be higher than the norm. Because of this, they did not demonstrate anxiety likely to manifest itself in less able swimmers' quest for survival, and thus further study with less able swimmers is warranted. Second, the sample size was small, and therefore the power of the findings requires further validation with a larger sample size. Third, the participants were fully aware of the demands of the tasks, so the element of surprise typical of unintentional immersion incidents and subsequent effect on performance was not replicated. Fourth, the tasks were simulations of open-water drowning situations but took place in the relatively benign environment of a heated outdoor swimming pool. Fifth, funding constraints placed limitations on the number of IMUs available; further studies using multiple sites, as discussed, is recommended. Sixth, individual testing with IMUs was labor-intensive and required precision in observation and tracking of data in real time; therefore, application in studies where such resources are not available may compromise the accurate use of IMUs. These limitations notwithstanding, the results of this study suggest that IMUs offer promise of exciting possibilities in future drowning prevention research.

Recommendations

Based on the evidence provided by the data and experience gained from conducting this study, the authors make the following recommendations:

- The water competencies and protocols developed and tested in this study provide a suitable basis for future testing but may require modification for lesser able groups.
- ODBA is an appropriate measure of dynamic movement and a proxy measure of energy expenditure in a drowning survival situation.
- Placement of IMUs on the wrist for arm propulsion measurement and the lower back for body positon would provide valuable information on swimming locomotion and flotation.
- Comparisons of ODBA between differing swimming strokes (especially those with in-water and out-of-water recovery when wearing clothes) and differing flotation techniques (especially horizontal and vertical flotation positions) would enhance our understanding of water competency and drowning prevention.

Conclusion

Results from this exploratory study demonstrated that IMUs have the potential to add to our understanding of what is physically required to combat the threat of drowning. The use of IMUs may help us understand how water competencies such as swimming locomotion and floating techniques may be best developed to withstand the onset of fatigue and minimize the risk of drowning in an emergency situation. With microchip technology now available relatively cheaply and usable in an aquatic environment, we have the opportunity to scientifically measure what is required of water competencies in simulated survival mode. The knowledge gained from further study may provide clearer direction for the teaching of water safety, which is a task too important to be left to chance, anecdotal evidence, or axiomatic wisdom alone.

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