Retention of Safe Diving Skills

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Abstract

This study investigated diving skill maintenance over an eight-month retention period following an intervention program. Thirty-four recreational swimmers with poor diving skills were measured before and immediately after a diving skills intervention program. Twenty-two returned for follow-up evaluation. Treadwater, Deck and Block dives were video-recorded, and maximum depth, distance, velocity, entry angle and flight distance were compared. Underwater hand and arm positions were examined. Pre-intervention, a breaststroke arm action before maximum depth occurred in 18% of all dives and 38% of Treadwater dives. This was eliminated post-intervention, improving head protection. The Treadwater dive elicited the greatest mean maximum depth, and ANOVA showed depth for this entry decreased (improved) following intervention and remained shallower at follow-up. Deck and Block dives also became shallower following intervention. As seven 10-minute skills sessions resulted in shallower dives with safer hand and arm positions, including safe diving skills in learn-to-swim programs can provide a diving spinal cord injury prevention strategy.

Introduction

The contribution of diving injury to the overall rate of spinal cord injury ranges from 2.3% in South Africa (Key & Retief, 1970) to 21% in Poland (Kiwerski, 1980). Recent Australian data indicates between 8 and 11% for aquatic spinal cord injury in the 1996-98 period (Cripps & O'Connor, 1998; O'Connor & Cripps, 1998). For males aged 15-24 years, aquatic spinal cord injury was the second greatest cause of spinal cord injury, exceeded only by transport accidents.

Stone (1981) reports impact velocities of 0.61 m/s and 1.22 m/s are sufficient to dislocate and crush cervical vertebrae, respectively. Velocities measured at maximum depth in 316 dives performed by recreational swimmers were all greater than 0.61 m/sec, and in 310 dives (98%), exceeded 1.22 m/s (Blitvich, McElroy, Blanksby, & Douglas, 1999). This indicates the potential for injury is inherent in every dive.

The importance of educational programs which increase awareness of dangers associated with diving has been highlighted (eg. Gilbert & Langendorfer, 1991; Milner, 1992; Scher, 1992; Tator & Edmonds, 1981; Torg, 1991; 1985). Some advocate a focus on teaching individuals how to dive safely (Blanksby, Wearne, & Elliott, 1996; Blanksby, Wearne, Elliott, & Blitvich, 1997; Blitvich et al., 1999; Damjan & Turk, 1995) but there is a dearth of information about the outcomes of such programs.

Poor diving skills increase the likelihood of sustaining a diving injury. Competitive swimmers perform many dive entries, but rarely sustain diving spinal cord injuries. Practising dive starts in a supervised environment with feedback from a coach assists competitive swimmers to enhance diving skills. Since the scoop and pike techniques have no demonstrated competitive advantage over flatter entries, Counsilman, Counsilman, Nimura and Endo (1979) recommended that they be discouraged.

Using maximum dive depth as the criterion risk measure, several technique factors can lessen the level of diving risk (Blitvich et al., 1999). For head and neck protection, arms should be maintained in extension beyond the head until after reaching maximum depth. Participants who performed shallower dives used steering techniques such as hyperextension of hands at the wrists, raising the upper trunk and arching the back, and slight hyperextension of the neck to minimise dive depth. They also locked the hands together to prevent them being forced apart by impact with the water. Some participants with poor diving skills deliberately performed a breaststroke arm action before reaching maximum depth, leaving the head unprotected during the downward underwater pathway.

To minimise risk of injury during instruction, the length of diving skills sessions and their placement within swimming lessons must be considered. Fatigue prior to practising a new skill can diminish acquisition and impair performance (Leonard, 1998). If the task has any element of danger, the performance decrement could lead to a serious accident (Schmidt, 1991). As the consequences of a diving accident can be catastrophic, diving should not be practised when fatigued.

Swimming pool diving spinal cord injury usually occurs in unsupervised recreational swimming (Kraus, Franti, Riggins, Richards, & Borhani, 1975; ThinkFirst Canada, 1995). Often, considerable time passes between learning safe diving skills as children and performing dive entries as an adult. Skill decay would be expected where a skill is learned but not performed for an extended period of time (Arthur, Bennett, Stanush, & McNelly, 1998). Accordingly, efforts should be made to maximise retention of safe diving skills as swimmers may not call upon the required skills for many months or years.

A meta-analysis of 52 empirical studies highlighted that mental rehearsal was more successful in enhancing retention of cognitive skills than physical skills but that, in the absence of mental rehearsal, physical skills will be better retained than cognitive skills (Arthur et al., 1998). Assuming mental rehearsal does not occur outside of diving instruction sessions, retention of safe diving skills should be enhanced by reducing the cognitive component of the skill. By engraining the cognitive decisions into the motor plan of action (i.e. “lock hands”, “steer up”) to automatically reproduce the response in the diving context, it is likely that the dive will be safer in the long term. Also, using one key set of instructions which applies in all settings reduces task complexity, moving it towards the closed end of the continuum which describes stability of the environment (Poulton, 1957). Hence, simplifying the diving task and eliminating the need for decision-making can lessen skill decay.

Leonard (1998) emphasised the importance of practising skills under the same sensory influences and context as those present when the skill is performed (ecological validity of task learning). This increases the probability of skilled performance outside of the practice setting. However, Annett (1979) noted difficulties when comparing ‘real-life’ tasks with ‘simulated’ tasks. There are two aspects to consider in ecological validity. The first is that real-life tasks are more complex than simulated tasks, and increased complexity can result in decreased retention. The second relates to the genuine interest of participants to acquire and retain proficiency. This is probably greater for real-life skills because they are seen as more relevant and, thus, are better retained (Driskell, Willis, & Cooper, 1992). Hence, well taught diving skills, with one key set of instructions designed to decrease complexity, are more likely to be retained.

Generally, skill decay is less following a high degree of overlearning during the initial skill acquisition period (Arthur et al., 1998; Driskell et al., 1992). Overlearning increases automaticity and is associated with decreased demand for concentrated effort by the learner. Learners become more confident, less stressed and anxious, thereby enhancing performance (Arthur et al., 1998). Also, evidence suggests retention is greater in those with higher skill at the end of the instruction period (Annett, 1979). Driskell et al. (1992) consider overlearning to be particularly beneficial in activities where correct first-trial performance is vital, such as in emergency procedures. Given the potential catastrophic outcome of the first dive performed after a lengthy non-practice period, instruction in safe diving skills should continue until a high level of skill is achieved. This could minimise skill decay once practice ceases.

One measure of learning is how quickly skill performance is relearned after a period without practice. That is, participants return to their former, high level of performance with only minimal ‘relearning’ or ‘practice’ (Annett, 1979). However, this has limited value in diving because every dive, including the first after a long absence (eg. over winter), must be safe due to potential dire consequences of just one poorly executed dive. DeMers (1994) reported that the typical spinal cord injury resulted from a guest’s first dive into a pool.

Because of the paucity of objective information regarding retention of motor skills in general, this study investigated the degree to which diving skills were retained eight months after an intervention program. If the positive effects of the diving skill intervention program were retained after a period without practice, it would confirm the importance of including such programs in learn-to-swim curricula and give direction to diving accident prevention strategies.

Methods

Participants

Thirty-four, first-year, university human movement majors (recreational swimmers, mean age 20.3 years, ± 4.8) with low diving skills were selected for an intervention program to improve diving ability (Blitvich, McElroy, & Blanksby, 2000) because they performed the deepest dives of 95 students involved in an earlier study (Blitvich et al., 1999). Studies were approved by the University of Ballarat Ethics Committee. Written informed consent was obtained and all 34 were invited to be re-assessed eight months after the intervention program (hereafter Post-8). The eight-month retention interval, considered long in terms of motor learning and skill retention, corresponded with the approximate period between the end of one summer and the beginning of the next and represents a realistic non-practice period. Twenty-two students attended Post-8. Those who did not return had either left university (three) or had prior commitments which could not be changed to enable their attendance (nine). To ensure participants who attended the immediate Post data collection but did not take part at Post-8 were not lower skilled participants, t-tests were conducted comparing pre-intervention dive depths for these groups.

Intervention program

The intervention program consisted of seven 10-minute sessions in which participants learned various techniques for steering their bodies by hyperextending the hands at the wrists, raising the upper trunk and arching the back, and slightly hyperextending the neck. Three key instructional cues emphasised throughout the program were: "Lock hands," "Lock head" and "Steer-up." Sessions were conducted following students' usual weekly swimming instruction classes. For a full description of the intervention program, see Blitvich et al. (2000).

Procedures

Before and after the intervention program, participants performed a dive from deck level to tread water after surfacing (Treadwater), and a dive from both deck level (Deck) and standard starting block of height 0.75 m (Block) prior to swimming the length of a 25 m pool. As diving injuries frequently occur during a person's initial dive into a pool (DeMers, 1994), a single entry was considered representative for each condition. Variables measured were maximum depth, distance at maximum depth, velocity at maximum depth, angle of entry and flight distance. Maximum depth was measured at the depth of the external auditory meatus as this landmark could be clearly identified. However, this is a conservative estimate of maximum depth, as the forehead would be approximately 0.15 m deeper than this point. All dives were video-recorded for later analysis, the details of which are provided elsewhere (Blitvich et al., 1999). The testing protocol used during the pre-intervention (Pre) and immediate post-intervention (Post) data collection sessions was repeated at Post-8. This enabled examination of retention of diving skill improvement without further practice during the intervening period.

For the 22 students who attended the Post-8 follow-up, a one-way repeated measures analysis of variance (ANOVA) with repeated measures on three levels was used for each variable at each diving condition. Where sphericity was not met, Greenhouse-Geisser correction was used. Where ANOVAs revealed significant main effects, simple contrasts and observed power were calculated to determine between which levels changes occurred. Traditional statistical analyses would recommend selection of an alpha level of .01 to control for experiment-wise error across multiple ANOVAs. However, comparisons were made with significance set at .025 for all tests to guard against ignoring a meaningful result in the real world setting.

Separation or pulling back of the hands was recorded from underwater video-recordings.

Results

Attrition

Because of some participant attrition over the study duration, it was important to ensure that those who withdrew were not the lowest in skill. Hence, t-tests were conducted comparing pre-intervention dive depths of participants who took part in the follow-up with those who attended the immediate post data collection but did not return for follow-up. Results showed that those who attended all sessions had a lower skill level prior to intervention compared to those who did not attend all sessions [$t(32) = 2.383$, $p = .02$]. Thus, the results of the retention study could be considered to be robust, as the retention group demonstrated a lower skill level prior to intervention but, as will be shown, improved following intervention and maintained this improvement over the retention period.

Observational assessment of diving technique

Observation of all dive entries showed participants did not lock their hands together on entry in 64% of dives, pre-intervention. Hand position on entry for these students ranged from almost touching to shoulder width apart. This percentage fell to four percent at Post, then increased slightly to 11% at Post-8. In 18% of pre-intervention dives, participants pulled their arms backwards in a breaststroke-like arm action before or at maximum depth, leaving the head completely exposed and unprotected. For the Treadwater condition, this occurred in 38% of dives pre-intervention. This action was completely eliminated after intervention, with none of the participants performing this action at either Post or Post-8.

Empirical analysis of diving technique

Means and standard deviations for measured variables are included in Table 1.

*****Please insert Table 1 about here*****

Results of one way repeated measures ANOVAs with three levels on the repeated measure (Pre, Post, and Post-8) using maximum depth, distance at maximum depth, velocity at maximum depth, entry angle and flight distance as dependent variables in separate analyses, are reported in Table 2. Observed power, effect size and simple contrasts are included also, comparing Pre with Post; Pre with Post-8; and Post with Post-8.

*****Please insert Table 2 about here*****

Treadwater

For the Treadwater dive, significant results were found for maximum depth, velocity at maximum depth and flight distance. Observed powers for these main effects ranged between .948 and .980. Simple contrasts showed a significant decrease in maximum depth from Pre to Post (33.7%) and Pre to Post-8 (30.1%). There was no significant difference between Post and Post-8. Velocity at maximum depth increased at both Post (18%) and Post-8 (16%) when contrasted with Pre. No change was observed between Post and Post-8. The same pattern was observed for flight, which increased from Pre to

Post (7.5%) and from Pre to Post-8 (10.3%). No change occurred between Post and Post-8.

Deck

The same variables (maximum depth; velocity at maximum depth; and flight) showed significant main effects for the Deck dive. Observed powers ranged from .535 to .981. Simple contrasts showed depth decreased significantly between Pre and Post-8 (18.8%) only. Velocity was increased between Pre and Post (16.9%) and Pre and Post-8 (20.8%). There was no difference between Post and Post-8. For flight, significant contrasts occurred between Pre and Post-8 (9.7 % increase) and Post and Post-8 (5.5% increase).

Block

For the Block condition, maximum depth followed the same pattern as for Treadwater, with observed powers between .598 and .997. Depth was significantly reduced in comparison to Pre at both Post (28.8%) and Post-8 (24.7%). No change was observed between Post and Post-8. Velocity at maximum depth repeated the pattern for Treadwater and Deck, increasing both Pre to Post (26.8%) and Pre to Post-8 (24.6%). No change occurred between Post and Post-8. Flight was unchanged in the Block condition, however distance at maximum depth showed an increase from Pre to Post-8 (7.2%).

Discussion

Key factors for dive safety are hand and arm position, and dive depth. Locked hands and an extended arm position protect the head from impact with the pool bottom or upslope, while shallow dives help to minimise the risk of diving injury. Consistent application of these techniques is required to ensure the retention of safer diving skills.

In the Pre data collection, many participants dived with their hands close, but not locked together. While this position provides some protection, at times arms were driven further apart by the force of impact with the water. During the intervention program, the importance of locking hands together was emphasised. The lesser skilled divers selected for this study were able to acquire this technique, and demonstrated relatively good retention of this change following the non-practice period. Those who failed to lock hands together at follow-up were the same people who had done so during pre-intervention testing. Hence, for at least some people, changing old habits was difficult. This reinforces the importance of learning the correct techniques for safe diving in the first instance, rather than needing to correct improper and unsafe techniques after they have been automated.

Pulling both arms backwards in a breaststroke-like action before, or at, maximum depth was completely eradicated following the intervention program and fully retained for all participants over the retention period. This dangerous manoeuvre leaves the head and neck exposed without protection at its deepest point and occurred in a large proportion of dives prior to the intervention program. Elimination of the breaststroke arm action alone would justify a diving education program similar to the intervention in this study.

While hand and arm positions are critical in safer dives, maximum depth reached in a dive is probably the single most important measure of danger of contacting the bottom or upslope of a pool. The Treadwater dive was the deepest and, thus, most dangerous dive pre-intervention. It is also the dive entry most likely to be used by a recreational swimmer, entering the water to ‘play’ rather than to swim laps. Significantly shallower maximum depth was achieved for Treadwater after intervention and was retained throughout the non-practice period. Hence, a comparatively short period of skill instruction resulted in a relatively permanent change in this important measure.

The Block condition was the next deepest dive pre-intervention, and followed the same pattern as Treadwater for depth. For Deck, mean maximum depth did not decrease significantly with intervention until the Pre-Post-8 comparison. The deck dive was already the most shallow and safe dive prior to intervention (0.53 m at the ear) and provided least opportunity for improvement. At an individual level, the student who performed the deepest deck dive pre-intervention (0.96 m) improved the most after intervention (Post-8, 0.68 m).

Velocity at maximum depth for Treadwater, Deck and Block dives was significantly greater after intervention, and this increased velocity was retained to Post-8. Although increased velocity might be perceived to represent increased risk, it is contended that the key factor in reducing risk of injury is to decrease the depth of dive. Therefore, the significantly higher velocity was not considered a major safety hazard, because it was achieved at shallower depth. In every instance, before and after intervention, the recorded velocity at maximum depth was greater than that considered sufficient to cause spinal injury should impact occur (Stone 1981).

Visual inspection of video-tapes suggested increased velocity could partly be attributed to improved streamlining of the body with the arms extended beyond the head and squeezed against the ears. It is also possible that increased force was applied against the block with a more confident ‘spring’ at take-off. The major contribution to higher velocity at maximum depth occurred as a result of subjects steering-up earlier in the underwater decelerating phase. In this circumstance, increased velocity, paradoxically, is associated with more skilful, confident and safer dives.

Distance from the wall at which maximum depth was achieved only reached significance on one occasion, the comparison between Pre and Post-8 for Block, showing a small increase of 7.2%. This relatively consistent position at maximum depth is important considering that following diving skills instruction, maximum velocity increased for the Treadwater, Deck and Block conditions. The most plausible explanation for not increasing distance at maximum depth despite increased velocity is successful implementation of steering-up techniques, enabling divers to surface over a shorter distance even while travelling faster. Participants in the study received less instruction in the Block condition than from deck level for the Treadwater and Deck dives. This may provide an explanation for the different result for the Block condition.

The ability to retain steering-up skills without continued practice demonstrates that participation in the intervention program resulted in relatively permanent improvements in diving safety. This is important given the number of diving spinal cord injuries resulting from impact with the pool upslope in the transition from deep to shallow water. With good steering-up skills it is likely that this method of injury could be avoided.

The mean flight distance for Block dives recorded at Post-8 (2.86 m) is similar to those recorded by Pearson (1998) in young competitive swimmers who have not achieved adult strength levels. Flight distances achieved by competitive swimmers performing dive starts from blocks range from 2.85 m in a study of age group swimmers (mean age 14.8 years) (Pearson et al., 1998) to 3.91 m for male college age swimmers (Lewis, 1980).

For Treadwater and Deck conditions, mean flight distance increased over the study duration. Pre to Post comparisons showed a significant increase in flight distance for Treadwater following intervention. For Deck, the increase in flight distance did not reach significance until Post-8. No significant differences in flight distance were found for Block. Increased flight distance for Treadwater and Deck but not Block may have been due to teaching progressions including many more dives from deck level than from blocks, leading to greater confidence from the deck. Hence, participants applied more force at take-off from the deck than from blocks, resulting in increased flight distances from the deck. This finding is consistent with the increased distance at maximum depth found only in the Block condition.

The results of this study have implications for public safety campaigns in diving skills, given the study included several important design factors which are often lacking in evaluation/retention studies. The long-term tracking of participants over a relatively extended period of eight months is rare (Arthur et al., 1998). Pre and immediate post evaluations, coupled with eight-month post intervention assessment, provided a strong indication of retention after implementing a focused ‘learn-to-dive’ program.

The current study included a 245-day non-practice interval which could be considered very long compared with other retention studies. Only 8% of studies reviewed by Arthur et al. (1998) had non-practice periods of more than 180 days. Retention intervals less than seven days were reported for 52% of studies, whilst 70% of studies had intervals less than 90 days. Given that skill decay generally increases as non-practice intervals increase, it is encouraging that a high level of diving skill improvement was retained in the current study.

Transfer of gliding and steering activities taught in the early stages of the intervention program to the diving action taught later in the program was enhanced by the faithfulness of the simulation (Leonard, 1998). Although gliding and steering were initially performed by pushing from the wall rather than a head first entry, the skills necessary for gliding and steering were identical to those used later for diving. The risk of injury during the learning phase was minimised because the skills required to decrease the danger inherent in diving were learned without head first entries. This enhanced transfer of skill resulting in participants performing shallower dives when head first entries were introduced. Magill (1998) discussed the importance of the transfer principle when learning skills with an element of danger such as diving.

According to Fisk and Hodge (1992) the more complex a task, the more quickly skill decays. This study minimised task complexity by using a progressive, practice sequence carefully designed to allow mastery of one stage before moving on to the next and taught by a skilled physical education teacher. By building on well-learned skills, participants proceeded onto the next stage without problems. The teaching methodologies used in this study emphasised the need to perform safe, skilled dives on every occasion when using a head first entry. The consistent use of three key phrases “lock hands,” “lock head” and “steer-up” provided constant reminders of the features to be implemented to improve diving safety. This simple list minimised the need for decision making when diving and enabled increased automation of the skill, maximising the likelihood of reproducible, skilled performance in all diving contexts. The success of the intervention program could, at least in part, be influenced by the selection of an appropriate sequence of progressions taught by a competent motor skills specialist teacher to achieve a low risk dive.

Conclusion

The implementation of weekly, distributed practice sessions has been successful for the learning of safe diving skills. Young adult learners with poor diving skills who participated in the intervention program were able to maintain improvements in diving safety over a non-practice period of 245 days. If all recreational swimmers acquired the knowledge of the dangers inherent in diving and the motor skills necessary to perform low risk dive entries and used these skills during every head first entry, then the risk of sustaining a shallow water diving spinal cord injury could be minimised. Spending approximately 70 minutes on a diving skills program is a small time investment in a prevention strategy to protect against the possibility of a lifetime of tetraplegia following a diving accident.

Authors' Note

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Table 1. Means, Standard Deviations and Ranges

VARIABLE		TREADWATER N=22			DECK N=22			BLOCK N=22		
		Pre	Post	Post- 8	Pre	Post	Post-8	Pre	Post	Post-8
Maximum depth (m)	Min	0.58	0.18	0.28	0.14	0.14	0.14	0.30	0.26	0.28
	Max	1.40	0.98	1.55	0.96	0.72	0.68	1.18	0.84	1.18
	Mean	0.83	0.55	0.58	0.53	0.46	0.43	0.73	0.52	0.55
	SD	0.21	0.20	0.27	0.15	0.14	0.13	0.25	0.15	0.20
Maximum distance to maximum depth (m)	Min	2.62	2.84	2.76	2.88	2.76	2.66	3.35	3.18	2.94
	Max	4.46	4.86	4.18	4.35	4.28	4.18	5.96	4.56	4.74
	Mean	3.54	3.61	3.54	3.61	3.65	3.56	4.32	4.02	4.01
	SD	0.44	0.45	0.36	0.41	0.34	0.36	0.60	0.38	0.43
Velocity at maximum depth (m/s)	Min	0.92	1.44	1.06	1.42	1.56	1.67	0.72	2.22	1.73
	Max	2.47	3.28	3.03	2.63	3.14	3.25	3.61	3.36	3.50
	Mean	1.89	2.24	2.21	2.07	2.42	2.50	2.24	2.84	2.79
	SD	0.39	0.46	0.56	0.37	0.42	0.35	0.64	0.28	0.46
Angle of entry (degrees)	Min	7	6	14	0	10	11	2	18	11
	Max	59	51	55	50	38	47	45	46	51
	Mean	36	29	32	28	25	27	33	31	35
	SD	12	10	11	11	8	10	11	8	11
Flight distance (m)	Min	1.82	1.90	1.84	1.72	1.94	2.00	2.10	2.26	2.00
	Max	2.86	2.70	2.96	2.92	2.84	2.94	3.56	3.38	3.48
	Mean	2.12	2.28	2.34	2.27	2.36	2.49	2.75	2.77	2.86
	SD	0.26	0.23	0.25	0.26	0.24	0.25	0.36	0.30	0.36

Table 2. ANOVA Results for Pre, Post and Post-8

					Simple Contrasts								
Dive	Dependent Measure	Main Effect	Observed Power[a]	Eta Squared	Pre – Post	Observed Power[a]	Eta Squared	Post – Post-8	Observed Power[a]	Eta Squared	Post-8 – Pre	Observed Power[a]	Eta Squared
Treadwater	Maximum depth	.000*	.974	.553	.000*	.940	.486	.619	.077	.012	.002*	.840	.361
(n=22)	Distance at max. depth	.782	.086	.012									
	Velocity at max. depth	.002*	.948	.472	.002*	.881	.387	.838	.028	.002	.008*	.696	.290
	Entry angle	.044	.480	.269									
	Flight distance	.000*	.980	.566	.001*	.916	.414	.286	.113	.054	.000*	.988	.522
Deck	Maximum depth	.024*	.535	.197	.130	.225	.106	.092	.281	.129	.003*	.812	.345
(n=22)	Distance at max. depth	.484	.083	.031									
	Velocity at max. depth	.000*	.981	.569	.000*	.952	.452	.230	.141	.068	.000*	.996	.563
	Entry angle	.229	.199	.137									
	Flight distance	.001*	.946	.514	.045	.407	.178	.010*	.667	.278	.000*	.985	.513
Block	Maximum depth	.002*	.889	.464	.001*	.969	.435	.395	.078	.035	.001*	.931	.429
(n=22)	Distance at max. depth	.017*	.598	.212	.037	.441	.191	.792	.030	.003	.007*	.712	.297
	Velocity at max. depth	.000*	.997	.480	.000*	.983	.508	.517	.055	.020	.000*	.996	.564
	Entry angle	.097	.340	..208									
	Flight distance	.056	.436	.250									

*significant at $p < 0.025$

[a] Observed Power computed using alpha = .025