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Increasing functional variability in the preparatory phase of the take-off improves elite springboard diving performance

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Abstract

Purpose: Previous research demonstrating that specific performance outcome goals can be achieved in different ways is functionally significant for springboard divers whose performance environment can vary extensively. This body of work raises questions over the traditional approach of balking (terminating the take-off) by elite divers aiming to perform only identical, invariant movement patterns during practice. **Method:** A 12-week training program (two times per day; 6.5 hours per day), was implemented with four elite female springboard divers to encourage them to adapt movement patterns under variable take-off conditions and complete intended dives, rather than balk. **Results:** Intra-individual analyses revealed small increases in variability in the board-work component of each diver's pre- and post-training program reverse dive take-offs. No topological differences were observed between movement patterns of dives completed pre- and post-training. Differences were noted in the amount of movement variability under different training conditions (evidenced by higher NoRMS indices post-training). An increase in the number of completed dives (from 78.91 – 86.84% to 95.59 – 99.29%) and a decrease in the frequency of balked take-offs (from 13.16 – 19.41 % to 0.63 – 4.41%) showed that the elite athletes were able to adapt their behaviors during the training program. These findings coincided with greater consistency in the divers' performance during practice as scored by qualified judges. **Conclusion:** Results suggested that, on completion of training, athletes were capable of successfully adapting their movement patterns under more varied take-off conditions, to achieve greater consistency and stability of performance outcomes.

Keywords: Practice; Adaptive movement pattern; Neurobiological degeneracy

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Previous research has theoretically modeled the functional role of movement variability in skill performance from a range of perspectives including optimal control theory (Todorov & Jordan, 2002), the uncontrolled manifold hypothesis (Scholz & Schöner, 1999), and ecological dynamics (e.g., Davids, Glazier, Araujo, & Bartlett, 2003). These approaches acknowledge that some action parameters can be allowed to vary during performance, while others are more tightly constrained. They share a theoretical commonality in advocating that a range of deterministic and variable processes contributes to observed fluctuations in regulated and unregulated motor system degrees of freedom (DOF) during task performance.

In this study we adopted an ecological dynamics perspective to investigate whether elite divers could be trained to harness adaptive movement variability to achieve consistent performance outcomes. From this theoretical viewpoint, movement pattern variability is considered functional when it affords performers flexibility to adapt goal-directed actions to satisfy changing performance constraints (Barris, Farrow, & Davids, 2013). Consistent performance outcomes can be achieved by different patterns of coordination available through re-configuration of a joint's biomechanical DOF (Bernstein, 1967; Newell & Corcos, 1991). Functional movement adaptability requires the establishment of an appropriate relationship between *stability* (i.e., persistent behaviors) and *flexibility* (i.e., variable behaviors). In neurobiological systems, *degeneracy* – the ability of elements that are structurally different to perform the same function or yield the same output (Edelman & Gally, 2001) – provides the conceptual basis to explain the functional role of movement pattern variability in sport performance. System degeneracy provides sport performers with valuable complexity and resistance to perturbations. Mason (2010) identified signature elements of system degeneracy in neurobiology that help us understand how elite performers can functionally adapt motor behaviors to consistently achieve high levels of performance in sport. These compelling ideas show how subtle adaptations can occur in some parts of an ongoing action, expressed by small changes at certain joints and limb segments, rather than the replacement of a whole action with another, distinct action.

Degeneracy provides a powerful rationale for seeking adaptive behaviors from athletes during practice. These ideas imply how sport practitioners can help athletes develop their skills as they attempt to satisfy task constraints during training. Although goal-directed movement patterns might exhibit some structural regularities and similarities, elite performers should not be fixated on attempts to repeat a rigidly stable movement solution during practice. Rather, degeneracy provides a clear theoretical expectation that performance outcome consistency does not require the repetition of identical, putatively optimal movement patterns. Instead, movements can be ongoingly adapted in a functional way to allow skilled athletes to achieve consistent performance outcomes.

Evidence for these ideas in performance of sport-related tasks has emerged from studies of triple jumping (Wilson, Simpson, van Emmerick, & Hamill, 2008), basketball shooting (Button, MacLeod, Sanders, & Coleman, 2003), locomotion (Hamill, van Emmerick, & Heiderscheit, 1999), and pistol shooting (Arutyunyan, Gurfinkel, & Mirskii, 1968). These investigations have demonstrated that individual performers are capable of discovering different ways to achieve specific task goals, even under similar performance constraints, through the coordination and control of a variety of functional movement patterns (Chow, Davids, Button, & Koh, 2008; Edelman & Gally, 2001).

The possibility for specific performance goals to be achieved by varying movement parameters is clearly significant for practice in sports such as springboard diving where the external environment can be highly variable (Barris et al., 2013; Kudo, Ito, Tsutsui, Yamamoto, & Ishikura, 2000). Appreciating properties of the springboard is particularly important for understanding the variable nature of competitive and training environments in diving. For example, small increases in board oscillation (resulting from changes in location and magnitude of force application by athletes during feet-board contact in dive preparation) can lead to large increases in performance environment variability (the board oscillates more quickly or slowly depending on the nature of contact by the athlete).

This performance challenge has practical implications for understanding divers' training behaviors. For example, during dive preparation, if a diver lands away from the edge of the board, the capacity to generate enough height to complete the required rotations to execute the dive successfully may be constrained (Kooi & Kuipers, 1994; O'Brien, 1992). These insights are important since biomechanical analyses of preparatory movements in diving have highlighted the significance of the approach and hurdle steps for successful completion of the dive. Actions of divers *after* take-off are largely dependent on their *preparatory* actions on the board (Miller, 1984; Slobounov, Yukelson, & O'Brien, 1997). To cope with such a variable performance environment, elite divers and their coaches typically strive during practice to achieve a stable, highly reproducible and invariant movement pattern (Barris et al., 2013).

To contend with variability emerging from interactions with the springboard, current training practices in springboard diving allow elite athletes to balk, if they perceive that their preparation is imperfect. Balking occurs when a diver completes the preparatory phase on the board (approach and hurdle steps), but does not take-off to complete the aerial somersaulting phase of the dive (see Figure 1). An implication of this strategy is that divers tend to reduce the number of practice trials they undertake and only practice executing dives from what are perceived to be ‘ideal’ approach and hurdle phases. This ‘template-driven’ approach to training is somewhat dysfunctional since it can have detrimental effects in competition, where a two-point balking penalty or ‘no dive’ judgment (score of zero from all judges) can result. Consequently, elite divers often attempt to complete dives in a competitive performance environment that they would choose to balk on in training. Anecdotal evidence in the form of elite-level experiential knowledge from Greg Louganis, a four-time Olympic champion, supports the idea that balking should be avoided (Lowery, 2010). Louganis tended to view a poor take-off as an opportunity for a personal challenge.

****Figure 1 about here ****

With the potential for a 2-point penalty in competition there appears to be no advantage in balking on unsatisfactory take-offs during training, except when a serious injury threat is perceived by an athlete. Rather, it seems advantageous for elite athletes to gain experience in adapting to movement variability in the take-off due to environmental variations (e.g., an oscillating board), and attempt to complete a quality dive under varying take-off conditions. Despite clear theoretical and empirical support for the notion of functional variability in performance, to date, these ideas have not been tested in a sport training program. Here, we sought to investigate whether elite divers could functionally adapt their traditional training behaviors (emphasizing repetition of identical movement patterns or balking (abrupt discontinuation of take-off preparation)), by exploiting inherent system degeneracy. The aim of this training program, therefore, was to introduce the notion of functional variability to an elite high performance squad which had traditionally aimed to remove variability from performance through constant practice.

We sought to investigate whether a sample of elite divers were able to adapt their movement patterns regardless of the perceived quality of their preparatory movements on the springboard. We designed task constraints for an elite athlete training program which were *representative* of the competitive performance environment (Brunswik, 1956). The concept of representative design implies a high level of specificity between a training environment and competitive performance conditions (Pinder, Davids, Renshaw, & Araújo, 2011), induced by encouraging divers to practice movement adaptation because it is functional during competitive performance.

In line with previous research (Arutyunyan et al., 1968; Hamill et al., 1999; Wilson et al., 2008), we expected that elite divers would be able to successfully reduce the amount of balking during training and, like other highly skilled athletes, increase their capacity to complete dives under varied take-off conditions at the end of the training program. It was anticipated that greater levels of variability would be observed in the hurdle and approach phases of the take-off after the training program, but that greater stability would be observed in key performance outcomes (i.e., a rip entry into the water with minimal splash from a varied take-off movement pattern).

Methods

Participants

Four elite female springboard divers (mean age 20 ± 2.9); who were free from injury and currently in training (average 28 hours per week); were recruited for this study and provided written informed consent. The sample represented 100% of the elite female springboard divers in Australia at the time of the study. The performance level of the sample was truly elite with participants having experience of performing at world championship and Olympic level. The experimental protocols received approval from two local research ethics committees.

Training Program

Pre- and Post-Training Program Observation

Prior to the program, participants were observed during all training sessions (aquatic and dry-land training) for one week to record baseline measurements of balking frequency. The number of balked and completed dives were recorded for each individual and expressed as a percentage of dives attempted. On completion of the training program, the divers were observed for one further week to record behavior retention. To avoid unduly influencing training behaviors, these recordings were completed without each diver's direct knowledge of the research question.

Program Design

The design of this investigation involved a twelve-week, single-group training program with an elite athlete population who were analyzed performing complex multi-articular skills in their normal practice environment. As such, this naturalistic, unique, observational training program did not provide opportunities to follow traditional laboratory-based intervention methods: with large sample sizes, control groups, learning and detraining periods and follow-up retention tests. For this reason, a dive not included in the training program, but practiced as much, was used as a within-participant control condition. In a backward somersaulting dive, the diver takes off from a standing start on the springboard with her back to the water and rotates backwards. Back dives (with two and a half somersaults) were included as a control measure, as they received the same amount of coaching and training time as reverse dives, but were not included in the training program as they do not involve a 'walking' hurdle approach. Similarly, since the movement patterns of each elite participant were subjected to individualized analyses, it was decided not to examine group-level data, decreasing the need to include a separate control group.

Performance of each elite athlete was monitored throughout all training sessions (10 per week), to record any balks that occurred in both the aquatic and dry-land environments (springboards set up over foam pits and crash pads in a gymnasium). Divers were encouraged to continue with their coach-prescribed individual training programs, but to avoid balking except in instances where they felt unsafe or where injury may have occurred.

Testing Periods

Kinematic analyses of movement behaviors were conducted before and after the training program to compare the amount of variability present in the preparatory phase of the take-off. It was hypothesized that a post- training program analysis of movement kinematics would reveal greater variability between trials than those recorded prior to the initiation of the training program. Two-dimensional kinematic characteristics of the approach and hurdle phases were captured using one stationary camera (Sony HDV FX1 HDV 1080i) positioned perpendicular to the side of the 3.0 m diving board (at a height of 4.0 m and distance of 15 m) in the sagittal plane (approximately 90°) and recorded movements at 60 frames per second (Barris et al., 2013; Slobounov et al., 1997). A sufficient focal length was chosen that permitted the recording of the whole dive movement and allowed the digitisation of the relevant body markers (Slobounov et al., 1997). Divers completed five repetitions of one dive (a reverse two and a half somersaults pike) to measure their ability to perform consistently. Participants were informed that their performances would be recorded for technique analysis and were asked to perform as best they could, according to the normal competitive judging criteria.

Flat 14 mm tape was fixed to twelve lower body limb landmarks on both the right and left sides of the body (anterior superior iliac spine; thigh, knee, shank, ankle, toe), ensuring an optimal position for minimizing visual occlusion (Slobounov et al., 1997). Further markers were placed on the side of the springboard (at 0.5 m, 1.0 m, 1.5 m and 2.0 m from the oscillating end) in direct line with the camera for calibration of the filming environment and to assist with step and hurdle length measurements (Barris et al., 2013). The kinematic analysis of the approach and hurdle phases was achieved by manually digitizing the identified lower limb anatomical landmarks using PEAK Motus™ Motion Analysis Software (Oxford, United Kingdom). One video sequence was selected at random and digitized by the same observer on five occasions to ensure that reliable results were obtained through the digitizing process (Hopkins, 2000). Intraclass correlation coefficient values ranged between $R = 0.95$ and $R = 0.99$ indicating strong correlations between the repeatedly analyzed trials.

Each diver's movements on the springboard prior to take-off were analyzed during all ten trials (five before and five after the training program) including: step lengths during the forward approach; (two normal walking steps), the length of the hurdle step (long lunge like step), and the hurdle jump distance (two foot take-off one foot landing). All step and jump lengths were measured as the distance between heel strike and toe off. Additionally, hurdle jump height (distance between the tip of the springboard and toes); flight time during the hurdle jump and the maximum angle of springboard depression (the maximum angle the springboard moves below its horizontal resting position) during the hurdle jump landing, were also recorded.

Further, each participant's joint kinematics were analyzed at the same key events in performance (e.g., approach step, hurdle jump, flight time, and maximum board depression angle). Angle-angle diagrams (ankle-shank and shank-thigh) were used to qualitatively describe performance variability and assess the topological equivalence of pre- and post-training program dives (Bartlett, Wheat, & Robins, 2007). Topological changes in movement patterns can provide evidence that specific aspects of coordination have changed (Anderson & Sidaway, 1994; Chow et al., 2008). If the two shapes are topologically equivalent, then it can be assumed that the same skill is being performed (Bartlett et al., 2007). However, if one diagram has to be folded, stretched or manipulated to fit the other, it can be assumed that two separate skills are being performed. Previous investigations have used angle-angle plots to depict qualitative changes in intra-limb coordination as a function of practice, and normalized root mean square error (NoRMS) to assess variability in the relationship between joint angles (Chow, Davids, & Button, 2007; Chow et al., 2008; Sidaway, Heise, & Schoenfelder-Zohdi, 1995). By measuring the resultant distance between the angle–angle coordinate of a curve and the angle–angle coordinate of the mean curve at each instant, a root mean square difference is calculated at each point in time. These values are averaged across the entire trial and subsequently normalized with respect to the number of cycles. This method has been recommended for small trial sizes and normalized techniques, and has successfully detected changes in stability of coordination in both linear and non-linear data angles (Chow et al., 2007; Chow et al., 2008; Sidaway et al., 1995). Results were interpreted based on the assumption that, a higher index for NoRMS is indicative of greater variability in joint coordination over trials, whereas a lower NoRMS index will indicate lower levels of variability in intra-limb coordination (Chow et al., 2007). A kinematic analysis was conducted at the conclusion of the training program, one week after the last training session.

Finally, video recordings of five reverse dives and five back dives performed pre- and post-training were sent to five national and international level judges, who were also blind to the research question, for retrospective analysis (according to FINA judging rules (FINA, 2009-2013). The average score for each participant’s dives are presented in Figure 3. Lastly, a Wilcoxon Signed Rank test ($p < .05$) was conducted to evaluate whether divers showed greater variability in performance after the ‘no balking’ training program.

Results

Observations

Notational analysis of athlete balking behavior was conducted before the training program and showed that all participants balked more frequently in the pool (18.08% – 25.91% of all dives completed) than in the dry-land training center (7.11% – 16.86% of all completed take-offs), as reported in Table 1. Overall, observations revealed that the frequency of athlete's balks ranged between 13.16% – 21.09% of all dives attempted (pool and dry-land combined). At the completion of the training program, further notational analysis showed that all divers balked less frequently, terminating between 0.63 – 4.41% of all dive take-offs attempted. Although the percentage of balked take-offs recorded after the training program was numerically less than those recorded prior to the start of the training program for all participants, Wilcoxon Signed Rank tests revealed that no participant showed a statistically significant change in the number of balked take-offs before and after the training program ($p > .05$).

**** Insert Table 1 about here ****

Pre- and Post-Training Program Kinematics

Board-work

An intra-individual analysis was used to examine variability present in the divers' movements during pre- and post-intervention reverse dive take-offs. Descriptive statistics showed the existence of very small amounts of variability within pre- training program dives for all participants (see Table 2). However, more variability was observed after the training program in almost all measures (as evidenced by higher standard error values) for all participants. For example, Participant 1 showed more variability (SD) in the post-intervention tests in all measures except the board angle at landing (pre: 13.5° (.23), post: 15.3° (.21)). In contrast, Participant 3 showed more variability in the post-intervention tests in all measures except jump height (pre: 73.4 cm (2.11), post: 74.4 (1.97)). These findings were further supported by Wilcoxon Signed Rank tests, which indicated differences (pre- and post-training program) in springboard depression during the hurdle, $z = -2.85$, $p < .01$ and at jump landing, $z = -2.85$, $p < .01$.

Joint Kinematics

Ankle-shank and shank-thigh angle-angle plots were constructed for both lower limbs to depict qualitative changes in intra limb coordination between pre- and post-training intervention take-offs. Qualitative diagrams revealed the presence of individual differences in movement pattern coordination. No topological differences were observed between the movement patterns of dives completed before- and after the training program, for any of the elite participants, suggesting that similar movement coordination patterns were being organized in both conditions (see Figure 2). However, differences were observed in the amount of variability *within* conditions, with angle-angle plots demonstrating greater variability in the approach and hurdle phases of take-offs completed post- training program and less variability in pre- training program dive take-offs. This performance feature was further highlighted by the presence of higher NoRMS indices for dives completed post-training program relative to those completed pre-training program (see Figure 3).

****Insert Table 2 and Figures 2 & 3 about here ****

The judges' average scores (out of ten) for the reverse dives recorded pre- and post-training program showed greater consistency between trials for all participants at the completion of the training period (see Figure 4). For example, scores for the reverse dives of Participant 1 fluctuated between 4.0 and 7.0 in the pre-test, but were more stable in the post-test scoring between 7.0 and 8.0. Similarly, Participant 2 showed large fluctuations in performance in the pre- test, scoring between 5.0 and 8.0, before showing consistent performances in the post- test (average scores 7.5-8.5). These findings were further supported by a Wilcoxon Signed Rank test which indicated a difference, $z = -3.73$, $p < .01$ in the consistency of reverse dives performed pre and post training program. Conversely, the average scores reported for each athlete's back dives, recorded in the same sessions, showed no consistency in performance between pre and post training program conditions, $z = -1.92$, $p > .05$.

**** Insert Figure 4 about here ****

Discussion

Over a 12-week period, this training program analysis determined that elite athletes were able to adapt their movement patterns (the approach and hurdle phases of a multi-somersault springboard dive take-off) and stabilize performance outcomes (e.g., entry into the water). These performance adaptations were exemplified post-training by a reduction in the incidence of balking, an increased variability in the preparatory phase of the take-off and greater stability of performance outcomes.

As expected, post-training observations of the athletes' performance showed that all divers had reduced the number of balked take-offs during training sessions, suggesting that they were able to adapt their movement patterns during the springboard dives. The ability to solve the same motor problem by exploiting different or variable execution parameters becomes especially important when the external environment is dynamic, as skilled performance emerges from the interactive relationship between the performer, environment and task (Newell, 1986). A diversity of movement patterns may be functional in helping athletes cope with unpredictable environmental situations, in this case bouncing on an oscillating springboard (Araújo & Davids, 2011; Davids, Araújo, Button, & Renshaw, 2007).

Individual analyses of each diver's preparatory phases revealed no changes in the shape of the angle-angle plots between pre- and post-training, suggesting that similar movement coordination patterns were being organized in both conditions. However, quantitative analyses of variability within the different conditions revealed greater consistency and lower levels of variability in dives completed prior to the training program and greater variability in dives completed at the completion of the training program, as evidenced by the NoRMS indices. This result demonstrates flexibility in the athlete's performance. By practicing without balking, the divers were able to develop the capacity to adapt their performances, exploring different strategies and exploiting the most functional performance behaviors (Davids et al., 2007). This flexibility allows the athlete to adjust an already acquired skill by exploiting the most appropriate pattern for the actual task (Preatoni, Ferrario, Dona, Hamill, & Rodano, 2010).

Performance outcome measures (judged dives) were included in this study to observe whether performance consistency could be improved by removing balking from the training environment. Although no improvements were made in the *quality* of movement pattern execution, that is, magnitude of scores did not improve (the divers were capable of high scoring dives pre-training program, but did so irregularly), all athletes became more *consistent* in their reverse dive execution, as reflected in the judges' scores. No balks were recorded for any of the participants, which may account for the large levels of variability initially seen in the scores, when athletes attempted to execute dives from take-offs where they might have previously balked in practice. Towards the end of the program, as the athletes became more confident, diving from less comfortable hurdle steps, performance scores became more consistent. Conversely, the judge's scores for the four participants' back two and half somersault dives were inconsistent and fluctuated greatly from test to test before and after the training program. The ability of the athletes to execute both dives well, may be attributed to the large training volume, high repetition of skills and expert coaching. However, it is likely that *consistency* in execution of the reverse dive may have been the result of the training program, where the divers, like skilled athletes in previous studies, were able to demonstrate stability in performance outcomes by compensating for variability detected in the take-off. These findings highlighted the exploitation of system degeneracy in skilled athletes and are in line with performance-based data from other sports, demonstrating how functional movement pattern variability can afford greater flexibility in task execution (Button et al., 2003; Wilson et al., 2008).

Importantly, the introduction of functional variability in diving performance during practice appears to have had little impact on the emergent movement form and the judges' scoring. Consequently, it seems that the benefit of achieving performance outcome consistency during competition (avoiding any minor point deductions that may be associated with deviation from the movement criteria guidelines) outweighed the severe penalties imposed for either balking or executing a poor dive from an uncomfortable take-off. The results of this investigation, although relevant, need further support due to the sample size (which nevertheless constituted 100% of the elite divers with international competitive experience in Australia) and the limitations of the two-dimensional manual digitization methods used. The individualized analyses undertaken here provided some unique insights into how elite individuals can harness functional movement variability to enhance their performance. Further work is needed with a larger sample of skilled athletes before more general conclusions can be drawn.

What Does This Paper Add?

This investigation addresses a perceived imbalance in the motor behavior literature on the practical relevance of the theoretical issue of functional adaptive movement variability.

While there have been clear insights provided on the conceptual nature of movement pattern variability, as well as an abundance of empirical data emerging from performance-based, experimental analyses providing new perspectives on movement coordination, there have been no attempts to investigate applications of these ideas over an extended period in a high performance skills training program. This is an important and necessary contribution to our understanding of the role of inducing adaptive movement variability during an elite sports training program. It is extremely challenging to persuade the designers of training programs to allow their typical practice activities to be modified in the way described in this study.

To our knowledge, this study represents one of the first attempts to theoretically, empirically and practically integrate ideas of functional adaptive movement variability in a high performance training program with a sample of truly elite athletes. It provided us with some useful insights on how functional adaptive movement variability might benefit highly skilled individuals in performance contexts such as elite sport. Although the sample size might be considered small, by the standards considered typical in traditional laboratory-based experimental studies of motor behavior, these participants represented 100% of all elite Australian female springboard divers. They provided a coherent sample to study from a single unified training program, therefore reducing possible inter-individual or coach-induced variations due to background training experiences and cultural differences.

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Table 1. Divers’ pre and post intervention balk and completed dive frequencies and percentages

Pre Intervention Observation

	Dry-land		**Pool**		**Dry-land**	**Pool**	**WEEKLY**	**DRY-LAND**		**POOL**		**OVERALL**	
Participant	*Completed*	*Balk*	*Completed*	*Balk*	**TOTAL**	**TOTAL**	**TOTAL**	*% Completed*	*% Balk*	*% Completed*	*% Balk*	***% Completed***	**% Balk**
1	87	17	104	29	104	133	237	83.65	16.35	78.2	21.8	**80.59**	**19.41**
2	143	29	235	72	172	307	479	83.14	16.86	76.55	23.45	**78.91**	**21.09**
3	196	15	213	47	211	260	471	92.89	7.11	81.92	18.08	**86.84**	**13.16**
4	115	9	163	57	124	220	344	92.74	7.26	74.09	25.91	**80.81**	**19.19**

Post Intervention Observation

	Dry-land		**Pool**		**Dry-land**	**Pool**	**WEEKLY**	**DRY-LAND**		**POOL**		**OVERALL**	
Participant	*Completed*	*Balk*	*Completed*	*Balk*	**TOTAL**	**TOTAL**	**TOTAL**	*% Completed*	*% Balk*	*% Completed*	*% Balk*	***% Completed***	**% Balk**
1	102	2	134	6	104	140	244	98.08	1.92	95.71	4.29	**96.72**	**3.28**
2	164	0	256	3	164	259	423	100.00	0.00	98.84	1.16	**99.29**	**0.71**
3	114	4	168	9	118	177	295	96.61	3.39	94.92	5.08	**95.59**	**4.41**
4	205	1	268	2	206	270	476	99.51	0.49	99.26	0.74	**99.37**	**0.63**

Table 2. Pre and post intervention means and standard deviation at key events during the preparation and approach phases of a dive take-off

P		*Approach Step 1 (cm)*	*Approach Step 2 (cm)*	*Hurdle Step (cm)*	*Hurdle jump Dist (cm)*	*Jump Height (cm)*	*Hurdle Jump Flight (t)*	*Board Angle Hurdle (°)*	*Board Angle Landing (°)*
1	***Pre practice***	36.8 (0.663)	46.4 (0.749)	52 (0.945)	62 (1.140)	69.2 (1.562)	0.826 (0.014)	9.34 (0.157)	13.5 (0.234)
	Post practice	34.6 (1.364)	47.2 (1.655)	58.4 (1.887)	68.2 (2.245)	71.2 (2.200)	0.826 (0.024)	9.94* (0.304)	15.3* (0.212)
2	***Pre practice***	30 (0.707)	26.8 (0.663)	28.6 (1.166)	82.8 (1.393)	64 (0.707)	.65 (0.014)	13.46 (0.163)	15.98 (0.287)
	Post practice	32 (1.000)	30.4 (1.721)	31.6 (1.631)	79.6 (2.502)	71 (2.191)	.71 (0.017)	13.52* (0.159)	15.58 * (0.235)
3	***Pre practice***	26 (1.38)	37.6 (1.030)	26.4 (1.288)	113.2 (1.068)	73.4 (2.112)	.716 (.001)	11.4 (.123)	14.1 (.187)
	Post practice	26.4 (2.56)	35.4 (1.536)	23.8 (1.985)	113.6 (2.337)	74.4 (1.965)	.822 (.002)	11.7* (.154)	15.3* (.241)
4	***Pre practice***	33.2 (0.800)	40.0 (0.316)	34.2 (0.583)	24.6 (0.510)	54.2 (0.583)	0.946 (0.001)	8.36 (0.214)	12.86 (0.103)
	Post practice	30.8 (1.428)	38.6 (0.510)	33.6 (0.927)	35 (1.095)	54.2 (1.020)	0.862 (0.001)	9.6* (0.228)	13.36 * (0.317)

*Wilcoxon Signed Rank Test significant difference $p < .01$

Figure 1. An example of the approach (a b) and hurdle (c d e f) phases of a reverse dive take-off.

Figure 2. (a & b) Right Ankle -Right Shank Angle -Angle plots for Participant One Pre (a) and Post (b) training program, (c & d) Right Ankle -Right Shank Angle -Angle plots for Participant Two Pre (c) and Post (d) training program, (e & f) Left Shank -Left Thigh Angle -Angle plots for Participant Three Pre (e) and Post (f) training program, (g & h) Left Ankle -Left Shank Angle -Angle plots for Participant Four Pre (g) and Post (h) training program.

Figure 3. Corresponding NoRMS indices for each participant's intra-limb coordination plot displayed above in Figure 2.

Figure 4. Average performance scores for each participant's reverse (left) and back (right) dives pre- and post-intervention.