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MELBOURNE AUSTRALIA

*Increasing functional variability in the preparatory phase of the takeoff improves elite springboard diving performance*

This is the Accepted version of the following publication

Barris, S, Farrow, Damian and Davids, K (2014) Increasing functional variability in the preparatory phase of the takeoff improves elite springboard diving performance. *Research Quarterly for Exercise and Sport*, 85 (1). 97 - 106. ISSN 0270-1367

The publisher's official version can be found at  
<http://www.tandfonline.com/doi/abs/10.1080/02701367.2013.872220#.VrAorEBw6U8>  
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*This is an Accepted Manuscript of an article published by Taylor & Francis in Research Quarterly for Exercise and Sport on 2014, available online:*  
<http://www.tandfonline.com/10.1080/02701367.2013.872220> ”

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

**Sian Barris**

<sup>a</sup> *Queensland University of Technology, School of Exercise and Nutrition Sciences, Brisbane,  
Australia.*

<sup>b</sup> *Australian Institute of Sport, Leverrier Crescent, Canberra, Australia*

Tel.: +61 73823 1444; Email.: sian.barris@gmail.com

**Damian Farrow**

<sup>b</sup> *Australian Institute of Sport, Leverrier Crescent, Canberra, Australia*

<sup>c</sup> *Institute of Sport, Exercise and Active Living, School of Sport and Exercise Science,  
Victoria University, Melbourne, Australia*

**Keith Davids**

<sup>a</sup> *Queensland University of Technology, School of Exercise and Nutrition Sciences, Brisbane,  
Australia*

<sup>d</sup> *Centre for Sports Engineering Research, Sheffield Hallam University, UK*

27

## Abstract

28 **Purpose:** Previous research demonstrating that specific performance outcome goals can be  
29 achieved in different ways is functionally significant for springboard divers whose  
30 performance environment can vary extensively. This body of work raises questions over the  
31 traditional approach of balking (terminating the take-off) by elite divers aiming to perform  
32 only identical, invariant movement patterns during practice. **Method:** A 12-week training  
33 program (two times per day; 6.5 hours per day), was implemented with four elite female  
34 springboard divers to encourage them to adapt movement patterns under variable take-off  
35 conditions and complete intended dives, rather than balk. **Results:** Intra-individual analyses  
36 revealed small increases in variability in the board-work component of each diver's pre- and  
37 post-training program reverse dive take-offs. No topological differences were observed  
38 between movement patterns of dives completed pre- and post-training. Differences were  
39 noted in the amount of movement variability under different training conditions (evidenced  
40 by higher NoRMS indices post-training). An increase in the number of completed dives (from  
41 78.91 – 86.84% to 95.59 – 99.29%) and a decrease in the frequency of balked take-offs (from  
42 13.16 – 19.41 % to 0.63 – 4.41%) showed that the elite athletes were able to adapt their  
43 behaviors during the training program. These findings coincided with greater consistency in  
44 the divers' performance during practice as scored by qualified judges. **Conclusion:** Results  
45 suggested that, on completion of training, athletes were capable of successfully adapting their  
46 movement patterns under more varied take-off conditions, to achieve greater consistency and  
47 stability of performance outcomes.

48

49 **Keywords:** Practice; Adaptive movement pattern; Neurobiological degeneracy

50

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

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

61           In this study we adopted an ecological dynamics perspective to investigate whether  
62    elite divers could be trained to harness adaptive movement variability to achieve consistent  
63    performance outcomes. From this theoretical viewpoint, movement pattern variability is  
64    considered functional when it affords performers flexibility to adapt goal-directed actions to  
65    satisfy changing performance constraints (Barris, Farrow, & Davids, 2013). Consistent  
66    performance outcomes can be achieved by different patterns of coordination available  
67    through re-configuration of a joint's biomechanical DOF (Bernstein, 1967; Newell & Corcos,  
68    1991). Functional movement adaptability requires the establishment of an appropriate  
69    relationship between *stability* (i.e., persistent behaviors) and *flexibility* (i.e., variable  
70    behaviors). In neurobiological systems, *degeneracy* – the ability of elements that are  
71    structurally different to perform the same function or yield the same output (Edelman &  
72    Gally, 2001) – provides the conceptual basis to explain the functional role of movement  
73    pattern variability in sport performance. System degeneracy provides sport performers with  
74    valuable complexity and resistance to perturbations. Mason (2010) identified signature  
75    elements of system degeneracy in neurobiology that help us understand how elite performers

76 can functionally adapt motor behaviors to consistently achieve high levels of performance in  
77 sport. These compelling ideas show how subtle adaptations can occur in some parts of an  
78 ongoing action, expressed by small changes at certain joints and limb segments, rather than  
79 the replacement of a whole action with another, distinct action.

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

89 Evidence for these ideas in performance of sport-related tasks has emerged from  
90 studies of triple jumping (Wilson, Simpson, van Emmerick, & Hamill, 2008), basketball  
91 shooting (Button, MacLeod, Sanders, & Coleman, 2003), locomotion (Hamill, van  
92 Emmerick, & Heiderscheit, 1999), and pistol shooting (Arutyunyan, Gurfinkel, & Mirskii,  
93 1968). These investigations have demonstrated that individual performers are capable of  
94 discovering different ways to achieve specific task goals, even under similar performance  
95 constraints, through the coordination and control of a variety of functional movement patterns  
96 (Chow, Davids, Button, & Koh, 2008; Edelman & Gally, 2001).

97 The possibility for specific performance goals to be achieved by varying movement  
98 parameters is clearly significant for practice in sports such as springboard diving where the  
99 external environment can be highly variable (Barris et al., 2013; Kudo, Ito, Tsutsui,

100 Yamamoto, & Ishikura, 2000). Appreciating properties of the springboard is particularly  
101 important for understanding the variable nature of competitive and training environments in  
102 diving. For example, small increases in board oscillation (resulting from changes in location  
103 and magnitude of force application by athletes during feet-board contact in dive preparation)  
104 can lead to large increases in performance environment variability (the board oscillates more  
105 quickly or slowly depending on the nature of contact by the athlete).

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

117         To contend with variability emerging from interactions with the springboard, current  
118 training practices in springboard diving allow elite athletes to balk, if they perceive that their  
119 preparation is imperfect. Balking occurs when a diver completes the preparatory phase on the  
120 board (approach and hurdle steps), but does not take-off to complete the aerial somersaulting  
121 phase of the dive (see Figure 1). An implication of this strategy is that divers tend to reduce  
122 the number of practice trials they undertake and only practice executing dives from what are  
123 perceived to be 'ideal' approach and hurdle phases. This 'template-driven' approach to  
124 training is somewhat dysfunctional since it can have detrimental effects in competition,

125 where a two-point balking penalty or ‘no dive’ judgment (score of zero from all judges) can  
126 result. Consequently, elite divers often attempt to complete dives in a competitive  
127 performance environment that they would choose to balk on in training. Anecdotal evidence  
128 in the form of elite-level experiential knowledge from Greg Louganis, a four-time Olympic  
129 champion, supports the idea that balking should be avoided (Lowery, 2010). Louganis tended  
130 to view a poor take-off as an opportunity for a personal challenge.

131 **\*\*Figure 1 about here \*\***

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

145 We sought to investigate whether a sample of elite divers were able to adapt their  
146 movement patterns regardless of the perceived quality of their preparatory movements on the  
147 springboard. We designed task constraints for an elite athlete training program which were  
148 *representative* of the competitive performance environment (Brunswik, 1956). The concept



149 of representative design implies a high level of specificity between a training environment  
150 and competitive performance conditions (Pinder, Davids, Renshaw, & Araújo, 2011),  
151 induced by encouraging divers to practice movement adaptation because it is functional  
152 during competitive performance.

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

## 161 **Methods**

### 162 **Participants**

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

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**172 Training Program****173 Pre- and Post-Training Program Observation**

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

**181 Program Design**

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

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

### 201 **Testing Periods**

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

217 Flat 14 mm tape was fixed to twelve lower body limb landmarks on both the right and  
218 left sides of the body (anterior superior iliac spine; thigh, knee, shank, ankle, toe), ensuring an  
219 optimal position for minimizing visual occlusion (Slobounov et al., 1997). Further markers  
220 were placed on the side of the springboard (at 0.5 m, 1.0 m, 1.5 m and 2.0 m from the

221 oscillating end) in direct line with the camera for calibration of the filming environment and  
222 to assist with step and hurdle length measurements (Barris et al., 2013). The kinematic  
223 analysis of the approach and hurdle phases was achieved by manually digitizing the identified  
224 lower limb anatomical landmarks using PEAK Motus™ Motion Analysis Software (Oxford,  
225 United Kingdom). One video sequence was selected at random and digitized by the same  
226 observer on five occasions to ensure that reliable results were obtained through the digitizing  
227 process (Hopkins, 2000). Intraclass correlation coefficient values ranged between  $R = 0.95$   
228 and  $R = 0.99$  indicating strong correlations between the repeatedly analyzed trials.

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

238         Further, each participant's joint kinematics were analyzed at the same key events in  
239 performance (e.g., approach step, hurdle jump, flight time, and maximum board depression  
240 angle). Angle-angle diagrams (ankle-shank and shank-thigh) were used to qualitatively  
241 describe performance variability and assess the topological equivalence of pre- and post-  
242 training program dives (Bartlett, Wheat, & Robins, 2007). Topological changes in movement  
243 patterns can provide evidence that specific aspects of coordination have changed (Anderson  
244 & Sidaway, 1994; Chow et al., 2008). If the two shapes are topologically equivalent, then it  
245 can be assumed that the same skill is being performed (Bartlett et al., 2007). However, if one

246 diagram has to be folded, stretched or manipulated to fit the other, it can be assumed that two  
247 separate skills are being performed. Previous investigations have used angle-angle plots to  
248 depict qualitative changes in intra-limb coordination as a function of practice, and normalized  
249 root mean square error (NoRMS) to assess variability in the relationship between joint angles  
250 (Chow, Davids, & Button, 2007; Chow et al., 2008; Sidaway, Heise, & Schoenfelder-Zohdi,  
251 1995). By measuring the resultant distance between the angle–angle coordinate of a curve  
252 and the angle–angle coordinate of the mean curve at each instant, a root mean square  
253 difference is calculated at each point in time. These values are averaged across the entire trial  
254 and subsequently normalized with respect to the number of cycles. This method has been  
255 recommended for small trial sizes and normalized techniques, and has successfully detected  
256 changes in stability of coordination in both linear and non-linear data angles (Chow et al.,  
257 2007; Chow et al., 2008; Sidaway et al., 1995). Results were interpreted based on the  
258 assumption that, a higher index for NoRMS is indicative of greater variability in joint  
259 coordination over trials, whereas a lower NoRMS index will indicate lower levels of  
260 variability in intra-limb coordination (Chow et al., 2007). A kinematic analysis was  
261 conducted at the conclusion of the training program, one week after the last training session.

262 Finally, video recordings of five reverse dives and five back dives performed pre- and  
263 post-training were sent to five national and international level judges, who were also blind to  
264 the research question, for retrospective analysis (according to FINA judging rules (FINA,  
265 2009-2013). The average score for each participant's dives are presented in Figure 3. Lastly,  
266 a Wilcoxon Signed Rank test ( $p < .05$ ) was conducted to evaluate whether divers showed  
267 greater variability in performance after the 'no balking' training program.

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**Results**

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**Observations**

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

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**Pre- and Post-Training Program Kinematics**

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**Board-work**

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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

294 contrast, Participant 3 showed more variability in the post-intervention tests in all measures  
295 except jump height (pre: 73.4 cm (2.11), post: 74.4 (1.97)). These findings were further  
296 supported by Wilcoxon Signed Rank tests, which indicated differences (pre- and post-training  
297 program) in springboard depression during the hurdle,  $z = -2.85, p < .01$  and at jump landing,  
298  $z = -2.85, p < .01$ .

### 299 **Joint Kinematics**

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

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

313 The judges' average scores (out of ten) for the reverse dives recorded pre- and post-  
314 training program showed greater consistency between trials for all participants at the  
315 completion of the training period (see Figure 4). For example, scores for the reverse dives of  
316 Participant 1 fluctuated between 4.0 and 7.0 in the pre-test, but were more stable in the post-  
317 test scoring between 7.0 and 8.0. Similarly, Participant 2 showed large fluctuations in

318 performance in the pre- test, scoring between 5.0 and 8.0, before showing consistent  
319 performances in the post- test (average scores 7.5-8.5). These findings were further supported  
320 by a Wilcoxon Signed Rank test which indicated a difference,  $z = -3.73$ ,  $p < .01$  in the  
321 consistency of reverse dives performed pre and post training program. Conversely, the  
322 average scores reported for each athlete's back dives, recorded in the same sessions, showed  
323 no consistency in performance between pre and post training program conditions,  $z = -1.92$ ,  $p$   
324  $> .05$ .

325 **\*\* Insert Figure 4 about here \*\***

## 326 **Discussion**

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

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



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

354 Performance outcome measures (judged dives) were included in this study to observe  
355 whether performance consistency could be improved by removing balking from the training  
356 environment. Although no improvements were made in the *quality* of movement pattern  
357 execution, that is, magnitude of scores did not improve (the divers were capable of high  
358 scoring dives pre-training program, but did so irregularly), all athletes became more  
359 *consistent* in their reverse dive execution, as reflected in the judges' scores. No balks were  
360 recorded for any of the participants, which may account for the large levels of variability  
361 initially seen in the scores, when athletes attempted to execute dives from take-offs where  
362 they might have previously barked in practice. Towards the end of the program, as the  
363 athletes became more confident, diving from less comfortable hurdle steps, performance  
364 scores became more consistent. Conversely, the judge's scores for the four participants' back  
365 two and half somersault dives were inconsistent and fluctuated greatly from test to test before  
366 and after the training program. The ability of the athletes to execute both dives well, may be

367 attributed to the large training volume, high repetition of skills and expert coaching.  
368 However, it is likely that *consistency* in execution of the reverse dive may have been the  
369 result of the training program, where the divers, like skilled athletes in previous studies, were  
370 able to demonstrate stability in performance outcomes by compensating for variability  
371 detected in the take-off. These findings highlighted the exploitation of system degeneracy in  
372 skilled athletes and are in line with performance-based data from other sports, demonstrating  
373 how functional movement pattern variability can afford greater flexibility in task execution  
374 (Button et al., 2003; Wilson et al., 2008).

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

388

### **What Does This Paper Add?**

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

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

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

409

410

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

*Pre Intervention  
Observation*

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

*Post Intervention Observation*

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



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