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Do the kinematics of a baulked take-off in springboard diving differ from a completed dive?

Running title: Movement Kinematics in Springboard diving

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Abstract

Consistency and invariance in movements are traditionally viewed as essential features of skill acquisition and elite sports performance. This emphasis on the stabilisation of action has resulted in important processes of adaptation in movement coordination during performance being overlooked in investigations of elite sport performance. Here we investigated whether differences existed between the movement kinematics displayed by five, elite springboard divers (17 ± 2.4 years) in the preparation phases of baulked and completed take-offs. The two-dimensional kinematic characteristics of the reverse somersault take-off phases (approach and hurdle) were recorded during normal training sessions and used for intra-individual analysis. All participants displayed observable differences in movement patterns at key events during the approach phase; however, the presence of similar global topological characteristics suggested that overall, participants did not perform distinctly different movement patterns during completed and baulked dives. These findings provide a powerful rationale for coaches to consider assessing functional variability or adaptability of motor behaviour as a key criterion of successful performance in sports like diving.
Introduction

Historically, scientists have stressed the importance of understanding the mechanisms associated with optimising behaviour and how skilled individuals achieve repeatable movement performance outcomes (2009). Variability in movement can be described as the normal variations that occur in motor performance across multiple repetitions of a task (Stergiou, Harbourne, & Cavanagh, 2006). It has been argued that a reduction in movement pattern variability is a characteristic of expert performance (Ericsson, 2008) resulting in a decrease in performance variability as a learner becomes more skilful (Bootsma & van Wieringen, 1990; Higgins & Spaeth, 1972; O'Brien, 1992; Slobounov, Yukelson, & O'Brien, 1997). Based on these theoretical insights, some coaches, athletes and sport scientists believe that skilled performance in sport is characterised by a reduction of variability in movement patterns achieved through extensive training and practice over thousands of hours (Ericsson, Krampe, & Tesch-Römer, 1993; O'Brien, 1992; Slobounov, Yukelson, & O'Brien, 1997). Consequently, coaching practice has been dominated by highly repetitive training sessions which emphasise invariant repetition of a perceived optimal movement pattern (Brisson & Alain, 1996; O'Brien, 1992). This is particularly true of aesthetic sports, like gymnastics or diving, where movement form is a major task constraint. In these tasks, external environments can vary, yet great importance is placed on production of stable repeatable performance outcomes, which are judged subjectively using strict criteria-based guidelines for how actions should look (see the FINA handbook for detailed dive descriptions, (2009-2013). The existence of these performance criteria may further contribute to the athlete’s desire to assemble a reproducible, invariant movement pattern, rather than allowing and encouraging functional variability in the performance of a dive or gymnastic skill. It is important to note, that although divers in particular may find changes to movement patterns alter the execution of the task, ultimately influencing the performance outcome (e.g. changes
to foot placement on the spring board may influence final dive entry into the water), these variations are not directly assessed by the judges. Instead, judging focuses on the overall aesthetics of the movement and the resulting performance outcome.

Theoretical insights have since emerged from a number of empirical studies showing the potential of movement pattern variability to be functional (Arutyunyan, Gurfinkel, & Mirskii, 1968; Bootsma & van Wieringen, 1990). Movement pattern variability within expert individuals can be considered functional when it supports the performance flexibility needed to adapt to changing environmental constraints in order to achieve a consistent performance outcome. In sport performance, consistent performance outcomes can be achieved by different patterns of joint coordination available through the re-configuration of the joint's biomechanical degrees of freedom (DOF) (Bernstein, 1967; Davids & Glazier, 2010; Seifert, Button, & Davids, In Press). Movement pattern variability should not necessarily be construed as a negative feature of expert performance in sport. Rather functional levels of movement adaptability require the establishment of an appropriate relationship between stability (i.e., persistent behaviours) and flexibility (i.e., variable behaviours). This relationship is essential to skilled performance in many different sports. Expert performance is characterized by relatively stable movement patterns which lead to consistent outcomes over time, are resistant to perturbations and reproducible in that a relatively similar movement pattern may be assembled by athletes under changing task and environmental constraints. For example, it would be expected that experts could produce subtly nuanced performance behaviours which are not at all stereotyped and rigid, but rather flexible and adaptive to environmental variations.

According to these theoretical ideas, although their movement patterns might exhibit some regularities and similarities within their structural components, elite athletes should not be fixed into rigidly stable performance solutions, but should be encouraged to adapt their
actions in a functional way. In the engineering of automated control systems, *redundancy* is built in to allow system components to take over processes when a specific component fails (Mason, 2010). In complex neurobiological systems, *degeneracy*, the ability of elements that are structurally different to perform the same function or yield the same output (Edelman & Gally, 2001), is an adaptive property which supports the functional role of movement pattern variability for performance in sports like diving (Glazier & Davids, 2010). Essentially, degeneracy provides a strong expectation that performance outcome consistency should not require movement pattern consistency (Bartlett, Wheat, & Robins, 2007). Since skill adaptation is proposed to be the basis of performance expertise in dynamic environments (Araújo & Davids, 2011), the co-existence of various adaptive motor solutions within inherently degenerate neurobiological systems can be exploited to enable different system components to achieve the same performance outcomes, consistently (Seifert et al., In Press).

This crucial idea implies that a diversity of movement patterns may be functional in negotiating dynamic performance environments and may be particularly relevant in unpredictable environmental situations, such as controlling the bounce on an oscillating springboard (Araújo & Davids, 2011; Davids, Araújo, Button, & Renshaw, 2007). Appreciating the characteristics of the springboard are particularly important for understanding the variable environment within which divers train and compete. For example, increases in the oscillation of the board (resulting from changes in location and magnitude of force application during dive preparation) can lead to increases in the variability of the performance environment (the board oscillates more quickly or slowly). This performance challenge has practical implications for understanding divers' training behaviours. For example, during the preparation phase, if a diver lands back from the edge of the board, their capacity to generate enough height to complete the required rotations to complete the dive successfully may be constrained. One solution to this performance problem may be for divers
to baulk (not complete the take-off phase of the dive) and dive only when they have assembled an 'optimal' preparation phase during competition. Alternatively, during training, it may be more advantageous for elite athletes to gain valuable experience in compensating for variability in their movement patterns or environmental changes (e.g. an oscillating board) and attempt to complete a quality dive under varying take-off conditions. While previous research has theoretically and empirically supported the notion of functional variability in performance, there have previously been no attempts to introduce this important idea into an elite sport performance training programme.

Observations of the behaviours of high performance divers have revealed that, in attempts to practice only high quality dives and achieve invariant movement patterns, squad members ‘baulk’ frequently. A baulked dive is defined as a take-off where the diver completes the approach and hurdle steps (see Figure 1.), but aborts the intended movement before the take-off phase if he/she considers the preparation to be imperfect. Over a week of training, this approach can result in upwards of 100 baulks (per diver, approximately 20% of all dives attempted). This approach to training reduces the volume of practice achieved by an individual and can have detrimental effects in competition with a two-point baulking penalty or ‘no-dive’ result. Consequently, divers often attempt to complete dives in a competitive environment that they would not complete in training. Despite this common practice, currently, there is no empirical evidence to suggest the existence of differences (temporal, kinematic or kinetic) in the preparation phase of baulked and completed dives in high performance athletes. It is possible; therefore, that this training habit is predicated on the misconception that only the best dives must be practised at all times in order to enhance skill in a sport like diving. Put simply, divers may be baulking in response to variations in their approach phase, essentially, stopping and restarting instead of trying to adapt and use a different strategy for solving the movement problem.
Biomechanical analyses of the dive take-off have shown that the preparatory movements in diving (approach and hurdle phases) are the precursors that facilitate the actual execution of dives (Miller, 1984; Slobounov et al., 1997). These studies have revealed that preparation for aerial phase of the dive is most predictive of performance success. Efficient execution of these initial movements was observed to be vital for the overall achievement of the performance goal (a good approach and hurdle means good body position, good height off the board, good rotation and good entry into the water). For this reason, the preparation phase of the springboard dive was chosen for analysis in this study of the role of adaptive movement variability in elite sport performance.

It follows that, by only completing dives that follow an ideal preparation phase, skilled divers may not be affording themselves the opportunity to develop adaptive and flexible strategies to achieve a similar performance outcome goal (rip entry into the water with minimal splash), with a varied take-off movement pattern. Adaptive movement patterns may enable skilled performers to repeat attempts at the same skill, but with differing patterns of performance. This flexibility allows the exploration of different strategies to find the most proficient among the many available options, so that consistent performance outcomes can be achieved. The performance of true experts in sport warrants investigation since expertise is predicated on the adaptation of a performer’s intrinsic dynamics (inherent performance tendencies) to cooperate with the task dynamics (Davids et al., 2007). Davids and colleagues (2007) suggest that enhanced movement adaptability, can be trained during practice when the gap between an individual’s pre-existing movement repertoire (the number of available solutions) and the demands of the task are low. Consequently, the aim of this study was to
investigate whether observable differences actually existed between the movement kinematics displayed by elite divers in the preparation phases of baulked and completed take-offs. Due to their high skill level, it was predicted that individual analyses of elite springboard divers would reveal no differences in the movement patterns (i.e. no kinematic differences evidenced by no changes in coordination pattern shape) between completed and baulked take-offs. However, in light of the athletes’ goal to eliminate take-off variations during training, it was expected that the movement patterns in the preparation phase for completed take-offs would display greater consistency than in those take-offs where the athletes baulked (e.g. variations in the size of angle-angle coordination plot). To summarise, in this study we expected to see no differences in movement patterns, evidenced by no change in coordination modes, because the observed athletes are highly skilled. We also expected that the completed dives performed by the athletes would show greater consistency, evidenced by lower levels of variability in the coordination plots, because the divers would typically try to deal with preparation variability by baulking to remove it during performance.

**Method**

**Participants**

Five elite Australian springboard divers (4 female and 1 male; mean age 17.2 years ±1.6) from the National and State high performance squads who were free from injury and currently in training (average 28 hours per week) were recruited for this study and provided written informed consent. Characteristics of this elite group of participants are presented in Table 1. The experimental protocols received approval from two local research ethics committees.

**Insert Table 1 about here**
**Apparatus and Procedures**

Flat 14mm 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 minimising visual occlusion (Slobounov et al., 1997). Further markers were placed on the side of the springboard (at 0.5m, 1m, 1.5m and 2m 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.

Video-recordings of divers successfully completing take-offs or baulking were captured during two training sessions in the athletes’ normal training environments; the aquatic centre and the diving dry-land training centre. A baulked dive was defined as a take-off where the diver completed the approach and hurdle steps, but did not complete the take-off phase of the dive. In the pool, each completed dive (those that displayed an approach, hurdle, take-off, and aerial phase) was assigned a score (out of ten) based on the perceived quality of the take-off, aerial somersaults and entry into the water by a national team coach who was naive to the aims of the study. Dives that scored between 7.0 and 10 were classified as successful dives and included in the study as the completed dives. Dives that scored between 4.0 and 6.5 were classified as unsuccessful and those that scored lower than 4.0 were considered incomplete. None of these dives were included in this study. In the dry-land area, coaches identified take-offs and aerial somersaults as ‘good’ or ‘poor’. No scores were assigned to baulked take-offs in either environment.

During data collection, participants were asked to follow their normal individual coach-prescribed training programmes and were informed that video recordings (similar to those made at most training sessions) would be taken at various stages during the session for technique analysis. No additional specific instructions, corrections or comments were
provided to the athletes by the researchers during data collection, in order not to contaminate the data emerging from athlete performance during these sessions. Information regarding the research interest in baulking kinematics was also withheld from participants to prevent positively or negatively influencing performance. Dives from all take-off groups (front, back, inward and reverse) were recorded during these sessions, however only those from the reverse take-off group were used for analysis (in the reverse dive group, the diver takes off facing forward and rotates backward towards the board). Specifically, in the pool, the approach and hurdle phases of a reverse two and a half somersault with wrist first entry was used for analysis. In the dry-land environment, the approach and hurdle phase of a reverse somersault with feet first landing was used. To prevent the training environment influencing the analysis, recordings of baulked take-offs in the dry-land were compared to completed take-offs in the same environment. For each participant, five completed dives that met the selection criteria (score) and five baulks from the same environment were chosen at random for analysis. The two-dimensional kinematic characteristics of these take-off phases (approach steps and hurdle) were captured using one stationary camera (Sony HDV-FX1 HDV 1080i) positioned perpendicular to the side of the diving board in the sagittal plane (approximately 90°) in each environment and recorded movements at 60 frames per second (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). Kinematic analyses of the approach and hurdle phases of baulked and completed dives were achieved by manual digitisation of the key anatomical landmarks using PEAK Motus™ Motion Analysis Software (Oxford, United Kingdom). The data were filtered using a low-pass Butterworth digital filter.
Analysis

Data in this investigation were separated and analysed in two phases: board-work and joint kinematics. The data were analysed with SPSS (version 18.0.0) for windows software (SPSS, Inc, USA).

Board-work

Due to the limited number of expert participants available, traditional inferential statistics are not reported. Only descriptive statistics are presented. The mean and standard deviation values between completed dives and baulked take-offs for each participant were determined at all key phases during the dive preparation. The first phase examined the divers’ movements on the springboard. This analysis included: 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 hurdle jump and the maximum angle of springboard depression during the hurdle jump landing were all recorded.

Joint kinematics

The second phase analysed the participants’ joint kinematics at the same key events (e.g., approach step, hurdle jump, flight time, and maximum board depression angle) during baulked and completed dives. Angle-angle diagrams were used to qualitatively describe performance variability and assess the topological equivalence of two different skills (Bartlett, 2007). The topological characteristics of a movement describe the motions of the body segments relative to each other and changes in these patterns can provide evidence specific aspects of coordination change (Anderson & Sidaway, 1994; Chow, Davids, Button,
& Koh, 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. There are many different ways to measure variability between movement patterns over trials (Glazier, Wheat, Pease, & Bartlett, 2006) and in this study we used the normalised root mean square error (NoRMS) technique established by Sidaway and colleagues (Chow, Davids, & Button, 2007; Mullineaux, 2000; Sidaway, Heise, & Schoenfelder-Zohdi, 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).

Finally, one video sequence was selected at random and digitised by the same observer on five occasions to ensure that reliable results were obtained through the digitising process (Hopkins, 2000). Intraclass correlation coefficient values ranged between $r = 0.970$ and $r = 0.999$ indicating strong correlations between the repeatedly analysed trials.

Results

Board-work

An intra-individual analysis was used to examine differences in divers’ movement patterns during baulked and completed dive take-offs. Descriptive statistics showed the existence of small differences between baulked and completed dives for all participants at various key performance milestone events (see Table 2). For example, Participant One showed very similar average step lengths between baulked and completed dives, demonstrating only 1cm- 1.4cm differences between conditions during the initial three steps. The largest differences between baulked and completed take-offs were observed in Participants Two and Five, who showed differences of 18.8cm in hurdle step length and
9.6cm in approach step 1, respectively. Four participants showed large differences (5cm – 8cm) in the average jump height between conditions. Small differences were observed in the angle of board depression at landing between baulked and completed take-offs in all participants (2.5° – 4.8°).

**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 completed and baulked take-offs. Qualitative angle-angle diagrams demonstrated the presence of individual differences in movement pattern coordination (see Figure 2). No topological differences were observed within participants, suggesting that the same movement coordination pattern was being organised in both baulked and completed dive take-offs (see Figure 3). However, differences were observed in the amount of variability between patterns with angle-angle plots displaying greater variability in the approach and hurdle phases of baulked take-offs and less variability in completed dive take-offs. This performance feature was further highlighted by the presence of higher NoRMS indices for baulked dives relative to the completed dives (see Figure 2, also evidenced by the NoRMS indices presented below in Figure 4). While data displayed in Figures 2 is for participants one and three, these findings were representative across all participants.
Discussion

This study aimed to investigate whether observable differences existed between the movement kinematics of elite divers in the preparation phases of baulked and completed take-offs. As predicted, no differences in movement patterns were observed between completed and baulked take-offs. Specifically, individual analyses revealed no changes in the shape of the angle-angle plots between conditions for any of the participants, suggesting that no differences in movement pattern coordination existed between baulked and completed dives that might justify the abortion of an intended dive. In attempting to only practise high quality dives, many athletes have traditionally tried to eliminate take-off variations during training. Consequently it was expected that, because of this approach to training, the movement patterns of completed take-offs would display greater consistency than those take-offs where the athletes baulked. Quantitative analyses of variability within conditions, revealed greater consistency and lower variability amongst completed dives, and greater variability amongst baulked dives for all participants as evidenced by the NoRMS indices.

An examination of key events (e.g., step lengths, jump height) during the approach and hurdle phases of the take-off revealed observable differences between performance conditions for all participants. However, these differences were not observed in all participants at all key events suggesting that, overall, the hurdle and approach phases of completed dives were not completely different from those of baulked take-offs. Furthermore, it is possible that athletes may choose to abort a planned take-off when they detect variation from the highly practised movement pattern of the comfortable completed dives. Wilson and colleagues (2008) suggested that each phase of a skill may be affected by the preceding phases. For example, Participant Five displayed large differences between completed and baulked take-offs in the distance of 1st approach step (9.6cm). A slightly shorter or longer step than the athlete considers ideal, may impact on subsequent phases of the take-off,
creating perceptions of discomfort and resulting in the athlete baulking. Further, Wilson et al., (2008) propose that the ability of coordinative units to adapt to performance perturbations (e.g. variations in step lengths or foot placements on the springboard in diving) is crucial if the performer is to consistently achieve successful performance outcomes. Additionally, the results of this study suggest that there may not be a single key event that causes all divers to abort the take-off. For example; Participant One showed the largest difference between conditions in the average hurdle jump distance (8.4cm). Participant Two showed the largest difference between conditions in the average hurdle step distance (18.8cm). Participant Three showed the largest difference between conditions in the average hurdle jump height (7.8cm). Participants Four and Five showed the largest differences in average hurdle step (6.0) and first approach step (9.6cm) respectively.

An important characteristic of skilled performance is the precise tuning of an action to the changing circumstances of the environment captured by the information properties available (Savelsbergh & Van der Kamp, 2000). With repetition in practice, the strength of the coupling of environmental information to action may increase the stability of the movement outcome observed (Savelsbergh and Van der Kamp (2000). By only practising dives with good quality take-offs, divers may only be affording themselves the opportunity to develop strong couplings between information and movement under very specific performance circumstances. Consequently, in situations where the divers do not perform an ideal take-off (often in competition); they are unable to adapt ongoing movements to achieve performance outcome stability (rip entry into the water with minimal splash). By encouraging divers to minimise baulking during training and attempt to complete every dive, athletes may be able to strengthen the information and movement coupling in all circumstances, widening the basin of performance solutions and providing alternative couplings to solve a performance problem even if the take-off is not ideal (Higgins & Spaeth, 1972). Slobounov
and colleagues (1997) argued that skilful diving performance was characterised by significant variability of movement patterns in preparatory phases preceding the actual execution of the dive itself. Of particular interest was their finding that more complex dives showed less variability than simple dives. The authors argued that this finding may have been an indication of an expert diver’s ability to efficiently reduce the number of controlled elements that need to be regulated during difficult dives (Slobounov et al., 1997). An alternative interpretation of these results, however, could attribute the observed variability in the simple dives to the athlete’s ability to complete simple tasks under variable conditions. In this example, divers were asked to complete dives without somersaults. The simplistic nature of these tasks (and the extensive training history) may have meant that the divers were more willing to complete a dive with an ‘uncomfortable’ take-off. Because of this, they may have already developed skills allowing the successful completion of the dive under varied take-off conditions. Conversely, with more complex skills (dives with multiple somersaults), athletes may fear that they will not complete the required number of rotations without an ideal preparatory phase; and baulk; ultimately reinforcing the notion that a good dive can only be achieved from a good take-off. Unfortunately, the number of baulks that occurred during the data collection phase in that study was not reported.

Although previous research has shown that functional variability increases with task expertise (Arutyunyan et al., 1968; Bernstein, 1967; Davids & Araújo, 2010; Manoel & Connolly, 1995), the current investigation is unique since the sample of elite divers had actively attempted to phase out or minimise functional variability during training. These findings have shown that no differences exist between baulked and completed take-offs and provide a powerful rationale to encourage coaches to consider functional variability or adaptability of motor behaviour as a key criterion of successful performance in diving; rather than the ability of all performers to replicate an ideal movement template. This perspective is
in line with suggestions that skill acquisition might be better understood as skill adaptation. How changes to training practices might include or integrate functional variability in performance, and how this may impact on movement form, and ultimately performance outcomes in the form of judges’ scoring, remains an issue for future work. However, the benefit of achieving performance outcome consistency during competition (and any minor point deductions associated with deviation from the movement criteria guidelines) would outweigh the severe penalties imposed for either baulking or executing a poor dive from an uncomfortable, unpractised take-off.

In summary, it has been argued that variability is a necessary prerequisite to adaptation whether genetic or behavioural, and that the sources of variability are intrinsic to a neurobiological system (Klingsporn, 1973). The results of this investigation provided no evidence to suggest that different movement patterns existed between baulked and completed dives that might justify the abortion of an intended dive. Consequently, with no major differences in coordination patterns, and the potential for a negative performance outcome in competition, there appears to be no training advantage in baulking on unsatisfactory take-offs during training, except when a threat of injury is perceived by an athlete. The observation of similar movement patterns in baulked and completed dives is an interesting finding. Prior to this study it was not known whether the preparation phase differed between baulked and completed dives and the data reported here indicate that there were no reasons, from a movement kinematics perspective, for the elite divers to baulk. Since the results show that there are no performance advantages for the elite divers to baulk (indeed there are clear competitive disadvantages for this behaviour), the implication is that enhancing their movement adaptability would be far more beneficial.

A future training intervention, where participants continue with normal training practice but are not allowed to baulk, may be advantageous for developing skills to adapt to
variability in the movement patterns of the approach and hurdle phases or environmental changes (e.g. an oscillating board). Specifically, divers should aim for an optimal performance outcome (quality dive entry) on each dive; continuing with the dive approach and take-off regardless of the perceived quality of the preliminary lead-up. The results of this investigation, although relevant, must be considered with some caution due to the sample size (which constituted nearly 100% of the elite divers with international competitive experience in Australia), the small values and the limitations of two-dimensional manual digitisation. Consequently, further work is needed with a larger sample before more general conclusions can be drawn.
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