

How performance analysis of elite long jumping can inform representative training design through identification of key constraints on competitive behaviours

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1 How performance analysis of elite long jumping can inform representative training
2 design through identification of key constraints on competitive behaviours

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24 Abstract

25 Analysing performance in competitive environments enables identification of key
26 constraints which shape behaviours, supporting designs of more representative
27 training and learning environments. In this study, competitive performance of 244
28 elite level jumpers (male and female) was analysed to identify the impact of candidate
29 individual, environmental and task constraints on performance outcomes. Findings
30 suggested that key constraints shaping behaviours in long jumping were related to:
31 individuals (e.g., particularly intended performance goals of athletes and their impact
32 on future jump performance); performance environments (e.g., strength and direction
33 of wind) and tasks (e.g., requirement for front foot to be behind foul line at take-off
34 board to avoid a foul jump). Results revealed the interconnectedness of competitive
35 performance, highlighting that each jump should not be viewed as a behaviour in
36 isolation, but rather as part of a complex system of connected performance events
37 which contribute to achievement of competitive outcomes. These findings highlight
38 the potential nature of the contribution of performance analysis in competitive
39 performance contexts. They suggest how practitioners could design better training
40 tasks, based on key ecological constraints of competition, to provide athletes with
41 opportunities to explore and exploit functional intentions and movement solutions
42 high in contextual specificity.

43

44 Keywords: Performance analysis, long jump, representative learning design,
45 ecological dynamics, interacting constraints

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50 design through identification of key constraints on competitive behaviours

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52 Performance analysis in sport competition provides a quantitative link
53 between application, science and theory through an objective audit of athlete or team
54 behaviours (Hughes & Bartlett, 2002; McGarry, 2009). Performance is traditionally
55 described through evidence gained from notational analysis using competition,
56 technical and tactical indicators, as well as biomechanical technique descriptors
57 using kinematic and kinetic variables. In sports like track and field, performance
58 analysis has predominantly taken the form of movement analysis. For example, in
59 long jump, most analyses have been driven by biomechanical (e.g., Bridgett &
60 Linthorne, 2006; Hay, 1993) and motor control research (e.g., Glize & Laurent,
61 1997; Montagne, Glize, Cornus, Quaine, & Laurent, 2000) in controlled,
62 experimental or training environments (for an exception see Hay, 1988). Whilst
63 these studies have increased understanding of performance variables, insufficient
64 attention has been paid to analysing how long jump performance under the specific
65 constraints of competition environments might impact self-regulation in athletes.
66 Performance analysis, investigating competition behaviours, could enrich
67 understanding of self-regulatory interactions of athletes with the environment during
68 practice, revealing links between strategies, psychological states, emotions and
69 actions in individual athletes (Anderson, 2018; Hughes & Bartlett, 2002).

70 With a large range of variables available to analyse during long jump
71 competition performance, it is important that selection and interpretation of data are
72 guided by an appropriate theoretical framework. One proposed framework is
73 ecological dynamics which has enhanced the understanding of performance and

74 learning in a variety of sport contexts (Araújo, Davids, & Hristovski, 2006; Vilar,
75 Araújo, Davids, & Button, 2012; Warren, 2006). Ecological dynamics proposes how
76 human behaviour emerges through continuous interactions with affordances
77 (opportunities for action) available during performance, as multiple constraints act
78 on the (athlete-environment) system (Araújo et al., 2006; Araújo, Davids, & Passos,
79 2007; Gibson, 1979), providing rich information for self-regulation. Adopting this
80 theoretical framework to guide the analysis and interpretation of performance in long
81 jump, moves performance analysis beyond merely documenting discrete variables
82 from isolated events within competition. Such an approach allows for the
83 recognition of the conditioned coupling evident in dynamic performance
84 environments where constraints are deeply intertwined to shape athlete performance
85 (Vilar et al., 2012). Practically, identifying these constraints provide practitioners
86 with the opportunity to enhance the development of representative training designs
87 where intentions, perceptions and actions emerge in faithful simulations of a
88 performer's actions in competition (Pinder, Davids, Renshaw, & Araújo, 2011).

89 Current empirical research on how ecological dynamics can enrich
90 performance analysis highlights the unique interactions of individual, environmental
91 and task constraints that shape the emergence of athlete performance behaviours
92 (Travassos, Duarte, Vilar, Davids, & Araújo, 2012; Vilar, Araújo, Davids, & Bar-
93 Yam, 2013; Vilar et al., 2012). Previous research on personal constraints suggest that
94 a key variable that shapes the perception-action couplings of athletes is specific
95 intentions during performance. Athlete intentionality concerns the adoption of
96 specific performance goals (i.e., winning a competition, making the podium,
97 qualifying for a final, jumping conservatively to avoid a 'no-jump'), constrained by
98 the particular needs, wishes and desires of an athlete at a particular point in time

99 (Araújo, Davids, & Renshaw, 2018). To exemplify, intentions to make a ‘safe’ jump
100 or a jump for maximal distance clearly influence running velocity and foot
101 placement error on the take-off board (Bradshaw & Sparrow, 2000; Maraj, Allard, &
102 Elliot, 1998). This practical example illustrates how athletes might deliberately adapt
103 movement behaviours in order to complete a task in a *specific* way, related to current
104 performance goals or competitive needs. The successful (or unsuccessful) execution
105 of specific performance strategies is likely to impact future jump performance as the
106 athlete adapts to his/her emerging needs in an unfolding competitive event, with
107 interconnected performance trials. Each jump within a competition comprises a
108 complex system, a series of connected events to influence overall competitive
109 performance outcomes (Renshaw & Gorman, 2015). This complex system of
110 competitive jumps can be perturbed by emerging cognitive-emotional-physical
111 demands at a specific performance event (Headrick, Renshaw, Davids, Pinder, &
112 Araújo, 2015).

113 Environmental constraints, including physical (i.e., wind, ambient light,
114 temperature, altitude, air density) and social variables (i.e., family support, peer
115 groups, an evaluating audience and cultural norms) can also influence athletic
116 performance. In long jumping, the influence of wind speed and direction on jump
117 performance is unique as stability of running and jump components can be perturbed
118 during task execution. Mathematical modelling has suggested influences on long
119 jump distance of between 0.08-0.12 m for a 1 m/s increase or decrease in wind
120 velocity (de Mestre, 1991; Ward-Smith, 1985). The effects from drag during the
121 aerial phase and running velocity during the approach run are primary causes of an
122 increase in jump performance (Ward-Smith, 1985). The influence of wind on jump
123 performance is compounded by sport regulations preventing a change in the

124 direction of an athlete's run-up if there is a change in weather conditions during
125 competition (*Competition Rules 2014-2015*, 2013). This type of environmental
126 constraint emphasises the importance of attunement to potential variability in
127 performance conditions when preparing for competition by elite athletes.

128 Task constraints are more specific to performance contexts than
129 environmental constraints (Davids, Button, & Bennett, 2008) and include the rules of
130 a sport. In long jumping, the key rule is the requirement to keep the front foot behind
131 the take-off line to register a legal jump, constraining run-up strategies. Research on
132 the run-up approach in long jumping (e.g., Lee, Lishman, & Thomson, 1982;
133 Montagne et al., 2000) has demonstrated that the presence of the take-off board, in
134 comparison to jumping conditions with no take-off board, led to changes in foot
135 placement throughout the entire run-up as well as lower levels of footfall variability
136 (Maraj, 1999). The need to intercept an object or surface, such as a 20cm wide take-
137 off board, when completing a task *nested* at the end of a run-up (i.e., jumping) has
138 important implications for training design. Gait regulation strategies in run-ups with
139 the absence of a nested jumping task show few similarities with performance in tasks
140 requiring a jump at the end (Bradshaw & Aisbett, 2006; Glize & Laurent, 1997).

141 Identifying interacting constraints that shape exploration and utilisation of
142 affordances (opportunities for action) in competition provides practitioners with a
143 better understanding of the performance environment, thereby enhancing their
144 capacity to design more effective practice tasks. Ecological dynamics proposes how
145 training environments could be designed to provide athletes with opportunities to
146 attune and calibrate their intentions, perceptions and actions in the landscape of
147 affordances representative of competitive performance (Pinder et al., 2011). Such
148 learning designs can enhance athlete adaptation to the dynamics of a competitive

149 performance environment, ready to self-regulate their behaviours as a competitive
150 event unfolds. Currently, there is limited research investigating the constraints of
151 competition in long jumping and there is a need for a more in-depth analysis of
152 performance in elite long jump competitions. Consequently, this study aimed to
153 investigate how performance analysis, under the framework of ecological dynamics,
154 can lead to the identification of more contextual information for the design of
155 practice environments. These sources of information could better reflect the
156 intertwined interactions that emerge in between athlete intentions, perceptions and
157 actions in adapting to changing event conditions. Elite level long jumping will be
158 used as the exemplar, with key individual, environment and task constraints
159 identified through the statistical analysis of elite long jump competitions held
160 between 1999 and 2016. These competitions will include Olympic Games, World
161 Championships and Diamond league competitions.

162

163 Methods

164 Results from 108 (men = 56; women = 52) elite level long jump competitions
165 were obtained from publicly available online databases (www.iaaf.org.au &
166 www.diamondleague.com). These competitions included Diamond League
167 competitions staged between 2011-2016 (men = 42; women = 39) and World
168 Championship (men = 9; women = 8) and Olympic Game (men 5; women = 5)
169 competitions between 1999-2016. These events covered a total of 244 athletes
170 (male= 140; female=104) with 5 393 jumps (male = 2783; women = 2608) available
171 for analysis. Two jumps under 2 m were excluded as outliers in the men's dataset as
172 they were not reflective of a genuine attempt at a jump at that performance level.

173 Only performances of athletes in competitions where all wind (m/s) and horizontal
174 jump distance (m) data were available, were included in the analysis.

175 Candidate variables that may potentially impact on performance were
176 selected using an ecological dynamics rationale and the experiential knowledge of
177 elite long jumping coaches identified in previous research (e.g., Greenwood, Davids,
178 & Renshaw, 2012) (Table 1). For example, wind was selected as a candidate
179 environmental variable, since mathematical modelling has suggested that a 1m/s
180 increase or decrease in wind velocity has a 0.08-0.12 m impact on jump distance in
181 long jump (de Mestre, 1991; Ward-Smith, 1985). The conceptualisation that each
182 jump forms a part of a complex system, formed by a series of connected events
183 (Renshaw & Gorman, 2015), supports the inclusion in the analysis of performance
184 variables including previous round foul, round 1 foul, distance of round 1 jump,
185 medal position after previous foul, top 8 previous round and previous round jump
186 distance. It was predicted that these variables might impact the intentions or strategy
187 implemented by athletes throughout a competitive event, and subsequent movement
188 (re)organisation, depending on their competitive needs at a specific point in time
189 (Bradshaw & Sparrow, 2000; Maraj et al., 1998).

190 ##### Table 1 near here #####

191 To determine the effects of competition on jump distance, descriptive
192 statistics were calculated for each competition type with median jump distance
193 values compared using a Kruskal-Wallis test with a Bonferroni correction for
194 multiple comparisons ($p < .001$). Effects of year of performance on jump distance
195 was calculated using multiple linear regression ($p < .001$) and effects of round on
196 jump distance was determined using analysis of variance. Post-hoc procedures

197 (Tukey's HSD) determined where differences existed if statistically significant
198 differences were found.

199 To determine the variables that best predicted horizontal distance jumped, a
200 linear mixed model with main effects, interactions and random intercepts was
201 constructed. Univariate tests were first conducted to determine variables of
202 significance. Variables tested for statistical significance appear in Table 1 (excluding
203 'Previous round jump distance'). These variables were explored in order of
204 significance to determine the most parsimonious model explaining the most
205 variability and were assessed using Aikake's Information Criterion (AIC). Two-way
206 interactions only were considered for the purposes of the analysis. Statistical
207 significance level was set at $p = .05$.

208 Descriptive statistics were calculated on jump classification (legal and foul
209 jumps) with the effects of competition, round and time (years), on foul jumps made,
210 determined using chi-square test for association and effect sizes. To determine
211 variables which best predicted foul jumps, binary logistic regression was used.
212 Variables included in the regression calculation were identical to those used in
213 predicting jump distance with the addition of 'Previous round jump distance'.

214 Results

215 Table 2 provides descriptive statistics for jump distance and jump
216 classification across all competitions for both men's and women's competitions.
217 Multiple linear regression showed a statistically significant effect of the year of the
218 competition ($p < .001$) with mean distance jumped decreasing by 1.2 cms per year
219 for both men and women. The frequencies of foul jumps showed a significant annual
220 effect in women's competitions only, but the effect size was small ($\chi^2 = 25.6, p =$
221 $.019, \text{phi} = 0.099$).

222

Table 2 near here

223

Table 3 provides descriptive statistics of the effects of round on distance

224

jumped and foul jumps recorded for male and female competitions. Analysis of

225

variance demonstrated a significant effect of round ($F(5, 1931) = 5.425, p = .003$) on

226

distance jumped for male competitions only. Post hoc testing indicated significant

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differences in distances jumped between Round 1 and 2 ($p = .005$), Round 1 and 3 (p

228

$= .008$), Round 1 and 4 ($p = .000$) and Round 1 and 6 ($p = .004$). Overall, the number

229

of foul jumps was significantly different between rounds ($\chi^2 = 17.9, p = .003$) for

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female competitions only, with a small effect size ($\Phi = 0.083$). For both men and

231

women, total percentage of fouls was higher in the last three rounds (men: 31.49% &

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women: 32.45%), compared to the first three rounds (men: 29.66% & women:

233

26.85%).

234

Table 3 near here

235

Data on effects of competition on jump distance and classification for both

236

male and female competitions are provided in Table 4. For men, median (non-normal

237

distribution) jump distance for Diamond League (7.82 m) was significantly ($p <$

238

$.001$) shorter than World Championship (7.99 cm) and Olympic Games (8.03 cm). In

239

the female competitions, median distances ($p < .001$) and overall number of foul

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jumps were significantly different between competition types (Pearson Chi Square =

241

10.87, $p = .004$, $\Phi = 0.065$).

242

Table 4 near here

243

In determining the best predictors of jump distance in male competitions, the

244

main effects model showed a significant difference of competition type between

245

Olympic Games and both Diamond Leagues and World Championships. Estimated

246

marginal means revealed a larger statistical effect for Diamond Leagues with mean

247 jump distance value 16.8 cm (S.E. 0.64) less than that observed in Olympic Games
248 with World Championships found to be 8.6 cm (S.E.0.70) less. Of the other
249 variables, the largest effect on jump distance was found to be Round 1 jump distance
250 (coefficient = 0.374). Effects of wind (1 m/s increase in tailwind or reduction in
251 headwind) increased jump distance by 4.2 cm. In the interactions model, 'in medal
252 position after last round' with competition type, was significantly different between
253 the Olympic Games and Diamond Leagues ($p = .006$) only. Estimated marginal
254 means suggested that a jump into a medal position increased the value of the
255 subsequent round jump distance. Interactions of 'Distance of Round 1 jump' with
256 competition type were also significantly different between the Olympic Games and
257 the World Championships ($p < .001$).

258 For the women's competitions, a statistically significant difference was
259 found between jump distance observed in Diamond Leagues and Olympic Games,
260 with Diamond Leagues values being 12.8 cm shorter (S.E. 0.035) than Olympic
261 Games, based on the estimated marginal means. Other variables found to be of
262 significance in the main effects model were 'Round 1 jump distance' (coefficient =
263 .219), 'Medal position after previous round' (coefficient = 0.113), and the effect of
264 wind (5 cm increase in jump distance for 1 m/s increase in tailwind or reduction in
265 headwind). No variables within the interactions model were significant.

266 In determining the best predictors of foul jumps, no factor or covariate was
267 predictive of a foul jump in male competitions. Despite this observation, two factors
268 in the current model appear to increase the odds of a given jump being a foul, albeit
269 not statistically significantly. If a Round 1 jump was a foul, then the odds of the next
270 jump being a foul increased by a factor of 1.67 - regardless of the round.

271 Additionally, if the previous jump had been a foul, the odds of the next jump

272 resulting in a foul, was 1.56 higher than if it had not been a foul. For female
273 competitions, initial investigation showed that practically every factor measured was
274 a significant predictor of foul jumps, but the final, most parsimonious model
275 contained three terms: round, distance of first jump and previous jump being a foul.
276 The odds of foul jumps (compared to round 1) are significantly increased in rounds 4
277 (OR 1.615) and round 5 (OR 1.530). For distance of first round jump, a unit increase
278 (metre) in distance increased the odds of the next jump being a foul by a factor of
279 1.89. Thus, if an athlete made a first jump of 6.50 m, the odds of any remaining jump
280 in the competition being a foul were increased by a factor of 1.89, compared to a
281 competitor who made a first jump of 5.50 m. Furthermore, if an athlete recorded a
282 foul in the previous round, then the odds of recording a second foul in succession
283 were increased by a factor of 1.50.

284 Discussion

285 In this study, we sought to identify how the analysis of competition data,
286 framed by concepts from ecological dynamics, can provide a more nuanced
287 understanding of long jump performance. This relationship between performance
288 analysis and key tenets of the theory of ecological dynamics could assist
289 practitioners in designing more effective training environments to reflect the
290 intertwined interactions between intentions, perceptions and actions of athletes in
291 performance. Analysis of competitive performance data of elite male and female
292 long jumpers revealed that elite long jumping is defined by a mean jump distance of
293 7.81 m for men and 6.48 m for women. Interestingly, mean jump distance decreased
294 by 1.2 cm per year for both men and women. In classifying jump outcomes, the
295 percentage of jumps deemed fouls was 30.40% and 29.19%, respectively, for men

296 and women. The stagnation of long jump performance over time raises important
297 questions, given advances in technology and sport sciences (e.g., Balague, Torrents,
298 Hristovski, & Kelso, 2016; Pluijms, Canal-Bruland, Kats, & Savelsbergh, 2013) and
299 potentially point to the need to carefully consider training designs to enhance
300 performance.

301 Findings revealed how continuous interactions of individual, task and
302 environmental constraints influenced elite long jumping performance. The personal
303 constraint of an athlete's (tactically defined) intentions continuously shape
304 perception-action couplings during competition. It is these intentions, embedded
305 within specific performances, that frame the interactions of athletes with task and
306 environmental constraints to facilitate adaptive behaviours (Araújo et al., 2018). For
307 example, the lowest value for mean jump distance and lowest percentage of fouls
308 found in Round 1 suggests athlete intentionality on the first jump could be to record
309 a 'safe' jump. Round 1 jumps were also significantly shorter than jumps in Rounds
310 2, 3, 4 and 6 in the men's competitions. The notions of a 'safe' jump could be
311 interpreted as an athlete's deliberate adaptation of perception-action couplings (i.e.,
312 decrease in run-up velocity) to intentionally match his or her specific needs to the
313 competition demands at specific points in time (Araújo et al., 2018; Maraj et al.,
314 1998). The importance of the first round was also highlighted by its role in
315 predicting jump distance and fouls in future rounds across the competition. This
316 relationship between jump performances demonstrates that each jump is connected
317 and forms an event (Gibson, 1979) influencing emergent jump performance
318 (Renshaw & Gorman, 2015). The outcome of round 1 is, therefore, likely to impact
319 the athlete's intentions in subsequent rounds, depending on the needs of the athlete at
320 that particular point in the competition. Intentions, and hence perception-action

321 couplings, will be strongly influenced by an athlete's own goals, competitors'
322 performances and ultimately the rules of the sport (only the top 8 athletes at the end
323 of round 3, get three further jumps). For example, after a round 1 foul, an athlete
324 may place more emphasis on making a 'safe' jump (i.e., speed/accuracy trade-off) in
325 round 2 in order to increase the chances of making a legal jump that enables him/her
326 to receive three additional jumps after round 3. This conceptualisation of emergent
327 behaviours in long jump is an important development in better understanding
328 performance as a series of complex interconnected events rather than seeing training
329 as a series of isolated jumps, with important implications for training design.

330 The environmental constraint of wind was identified as a key influence on
331 long jump competitive performance. A 1 m/s increase in tailwind (or decrease in
332 headwind) increased jump distance for both women (by 5.0 cm) and men (by 4.2
333 cm). Previous research has attempted to determine the aerodynamic effects of wind
334 on jump performance (de Mestre, 1991; Ward-Smith, 1985) using mathematical
335 modelling. However, to date, no research has reported in-competition data.
336 Evidence on the impact of wind as an environmental constraint on jump performance
337 highlights the relevance of training designs which include experiences in variable
338 wind conditions.

339 As expected, a major task constraint is rule-based: that a 'no jump' is recorded
340 unless the take-off foot is behind the foul line. Satisfying this influential constraint
341 shapes athletes' behaviours and actions in seeking to intercept the take-off board
342 with the front foot. Foul jumps (at any time in a competition) were seen to increase
343 the odds of subsequent fouls later in the competition. With almost a third (men:
344 30.40% and women: 29.19%) of jumps being classified as fouls, each athlete's
345 tactical behaviours are influenced at any point in competition by these 'no' jumps.

346 For example, a foul jump in Round 1 increases pressure on an athlete to accurately
347 hit the take-off board in Rounds 2 and 3, whilst also needing to jump for distance to
348 qualify for the final three jumps. This increase in psychological and emotional
349 demands, along with the known implications for run-up velocity and foot placement
350 error on the take-off board when jumping for distance, defines how interactions
351 between different constraints impact behaviour in elite long jump performance.

352 The findings of the current study have important implications for the design
353 of representative training environments. Long jump coach education resources (e.g.,
354 Brown, 2013) typically fail to consider how competition behaviours can be invited
355 through the design of training environments. Simulating conditions of competitive
356 performance allows practitioners to model environmental and task constraints to
357 shape intentions, perceptions and actions influencing performance in elite long
358 jumping. Our analyses of elite competition revealed that the most influential
359 interactions were between: athlete intentionality, effect of wind (direction and speed)
360 and rules of the sport.

361 Identification of athlete intentions in the form of competition strategies
362 highlights the need for training to focus on adaptations needed to achieve specific
363 outcome goals, with athletes training in a series of connected jumps that replicate the
364 demands of competition. This form of 'within-session periodisation' can be achieved
365 by the creation of specific 'vignettes' for athletes, that seek to simulate the physical,
366 emotional and psychological demands of competitive performance environments
367 (Headrick et al., 2015). An exemplar scenario could focus on the context when an
368 athlete has fouled in the first two rounds and must record a jump of sufficient
369 distance in round 3 to qualify for a further three jumps. In this way, the reduction of
370 emphasis on constant repetition in some practice sessions can have a functional value

371 of highlighting focus on a single performance trial, which simulates competition
372 conditions. In this way practice task design could involve 'repetition without
373 repetition' as advocated by Bernstein (1967), for example, challenging athletes to
374 calibrate their actions (Van Der Kamp & Renshaw, 2015) to exploit variable wind
375 speeds and direction. Asking athletes to complete the run-up and jump in variable
376 wind speeds and direction during training will facilitate their attunement to variable
377 weather conditions and adaptation of movement patterns accordingly. Exploitation of
378 this environmental constraint in training will promote 'dexterity' (Bernstein, 1967) in
379 athletes and simulate the level of uncertainty that exists in competitive performance.
380 The high percentage of fouls across all competitions for both men and women,
381 suggests that there may be a failure to give due emphasis to the importance of legal
382 jumps in practice conditions (e.g., Brown, 2013). Whilst allowing fouls in training
383 may increase trial repetition (practice volume) and reduce performance complexity,
384 this approach fails to simulate the individual-environment relationships that
385 performers forge in the competition environment (Davids & Araújo, 2010; Renshaw,
386 Chow, Davids, & Hammond, 2010). Coaches need to recognise the take-off board as
387 a key affordance that athletes must attune to in order to enable the development of
388 functional perception-action couplings required in competition.

389

390 Conclusions

391 In summary, the theoretical framework of ecological dynamics suggests that
392 a more nuanced understanding of the complexities of long jump performance could
393 facilitate the design of more representative practice environments by practitioners.
394 We have considered how more contextual information from competitive

395 environments can enhance practice designs, following recent conceptualisation of the
396 use of ‘gold standard’ data in understanding sports performance constraints
397 (Anderson, 2018). Results from this study revealed three key constraints that shape
398 performance behaviours in both male and female elite long jumping: (i) athlete
399 intentionality, (ii) wind effects on run-up and jump phases, and (iii), adhering to
400 rules of the sport. The integrated manipulation of these key constraints in training
401 can provide opportunities for athletes to adapt to major physical and emotional
402 demands of performance environments. The use of ecological dynamics to guide the
403 analysis of competition data shows how performance analysis can be enhanced to
404 enrich the understanding of athlete interactions during competition. Recognising the
405 conditioned coupling evident in dynamic performance environments is a critical
406 advancement in understanding movement behaviours in individual sports.

407 Our findings suggested the need to move beyond reductionist approaches to
408 studying long jumping, currently provided by isolated biomechanical analysis of
409 single jumping events (Mendoza, Nixdorf, Isele, & Gunther, 2009). Future work
410 needs to embrace the complexity of competitive long jumping and adopt a more
411 inter-disciplinary approach to performance analysis in context. Future research could
412 also further our understanding of influential constraints on long jump performance
413 through accessing the experiential knowledge of expert coaches and athletes.
414 Integrating experiential knowledge with theoretical concepts and research data
415 would enhance understanding of interacting constraints impacting long jump
416 performance. It would also provide a basis for analysing how key long jumping
417 performance variables (such as in the run-up) may be shaped by competitive
418 performance contexts. This integrated approach would reveal informational
419 constraints that regulate athlete intentions, and perception-action couplings during

420 run-ups in sport tasks like long jumping, cricket bowling and gymnastics vaulting
421 (Greenwood, Davids, & Renshaw, 2014).

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427 References

- 428 Anderson, E. (2018, 6-8 June). *Representative movement behaviour measurement in*
429 *sport: Gold standard measurements versus gold standard data*. Paper
430 presented at the Measuring Behaviour, Manchester, United Kingdom.
- 431 Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of
432 decision making in sport. *Psychology of Sport and Exercise*, 7, 653-676.
- 433 Araújo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative
434 design, and correspondence between experimental task constraints and
435 behavioral setting: Comment on Rogers, Kadar, and Costall (2005).
436 *Ecological Psychology*, 19(1), 69-78. doi:10.1080/10407410709336951.
- 437 Araújo, D., Davids, K., & Renshaw, I. (2018). Cognition, emotion and action in
438 sport: An ecological dynamics perspective. In G. Tenenbaum & R. Eklund
439 (Eds.), *Handbook of Sport Psychology* (4th ed.).
- 440 Balague, N., Torrents, C., Hristovski, R., & Kelso, J. A. S. (2016). Sport science
441 intergration: An evolutionary synthesis. *European Journal of Sport Science*.
442 doi:10.1080/17461391.2016.1198422.

- 443 Bernstein, N. A. (1967). *The Control and Regulation of Movements*. London:
444 Pergamon Press.
- 445 Bradshaw, E., & Aisbett, B. (2006). Visual guidance during competition
446 performance and run through training in long jumping. *Sports Biomechanics*,
447 5(1), 1-14.
- 448 Bradshaw, E., & Sparrow, W. (2000). The speed-accuracy trade off in human gait
449 control when running towards targets. *Journal of Applied Biomechanics*, 16,
450 331-341.
- 451 Bridgett, L. A., & Linthorne, N. P. (2006). Changes in long jump take-off technique
452 with increasing run-up speed. *Journal of Sports Sciences*, 24(8), 889-897.
453 doi:10.1080/02640410500298040.
- 454 Brown, E. (2013). *A guide to teaching athletics in the school curriculum*.
455 Queensland.
- 456 *Competition Rules 2014-2015*. (2013). Monaco: International Association of
457 Athletics Federations Retrieved from <http://iaaf.org.au>.
- 458 Davids, K., & Araújo, D. (2010). The concept of organismic of asymmetry in sport
459 science. *Journal of Science and Medicine in Sport*, 13(6), 633-640.
- 460 Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: A*
461 *constraints-led approach*. Champaign, IL: Human Kinetics.
- 462 de Mestre, N. (1991). A mathematical analysis of wind effects on a long-jumper. *The*
463 *ANZIAM Journal*, 33(1), 65-76. doi:10.1017/S0334270000008626.
- 464 Gibson, J. J. (1979). *The Ecological approach to visual perception*. Boston, MA:
465 Houghton Mifflin.
- 466 Glize, D., & Laurent, M. (1997). Controlling locomotion during the acceleration
467 phase in sprinting and long jumping *Journal of Sports Sciences*, 15, 181-189.

- 468 Greenwood, D., Davids, K., & Renshaw, I. (2012). How elite coaches' experiential
469 knowledge might enhance empirical research on sport performance.
470 *International Journal of Sports Science & Coaching*, 7(2), 411-422.
- 471 Greenwood, D., Davids, K., & Renshaw, I. (2014). Experiential knowledge of expert
472 coaches can help identify informational constraints on performance of
473 dynamic interceptive actions. *Journal of Sports Sciences*, 32(4), 328-335.
474 doi:10.1080/02640414.2013.824599.
- 475 Hay, J. (1988). Approach strategies in the long jump. *International Journal of Sport*
476 *Biomechanics*, 4, 114-129.
- 477 Hay, J. (1993). Citius, altius, longius: The biomechanics of jumping for distance.
478 *Journal of Biomechanics*, 26(1), 7-21.
- 479 Headrick, J., Renshaw, I., Davids, K., Pinder, R. A., & Araújo, D. (2015). The
480 dynamics of expertise acquisition in sport: The role of affective learning
481 design. *Psychology of Sport and Exercise*, 16, 83-90.
482 doi:10.1016/j.psychsport.2014.08.006.
- 483 Hughes, M., & Bartlett, R. (2002). The use of performance indicators in performance
484 analysis. *Journal of Sports Sciences*, 20(10), 739-754.
- 485 Lee, D., Lishman, J., & Thomson, J. (1982). Regulation of gait in long jumping.
486 *Journal of Experimental Psychology*, 8(3), 448-459.
- 487 Maraj, B. (1999). Evidence for programmed and visually controlled phases of the
488 triple jump approach run. *New Studies in Athletics*, 14(1), 51-56.
- 489 Maraj, B., Allard, F., & Elliot, D. (1998). The effect of nonregulatory stimuli on the
490 triple jump approach run. *Research Quarterly for Exercise and Sport*, 69(2),
491 129-135.

- 492 McGarry, T. (2009). Applied and theoretical perspectives of performance analysis in
493 sport: Scientific issues and challenges. *International Journal of performance*
494 *analysis in sport*, 9(1), 128-140.
- 495 Mendoza, L., Nixdorf, E., Isele, R., & Gunther, C. (2009). *Biomechanical analyses*
496 *of selected events at the 12th IAAF World Championships in Athletics, Berlin*
497 *15-23 August 2009*. Retrieved from Germany:
- 498 Montagne, G., Glize, D., Cornus, S., Quaine, F., & Laurent, M. (2000). A
499 perception-action coupling type of control in long jump. *Journal of Motor*
500 *Behaviour*, 32(1), 37-43.
- 501 Pinder, R., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning
502 design and functionality of research and practice in sport. *Journal of Sport &*
503 *Exercise Psychology*, 33, 146-155.
- 504 Pluijms, J., Canal-Bruland, R., Kats, S., & Savelsbergh, G. (2013). Translating Key
505 methodological issues into technological advancements when running in situ
506 experiments in sports. *International Journal of Sports Science & Coaching*,
507 8(1), 89-103.
- 508 Renshaw, I., Chow, J. W., Davids, K., & Hammond, J. (2010). A constraints-led
509 perspective to understanding skill acquisition and game play: A basis for
510 integration of motor learning theory and physical education praxis? *Physical*
511 *Education & Sport Pedagogy*, 15(2), 117-137.
- 512 Renshaw, I., & Gorman, A. (2015). Challenges to capturing expertise in the field. In
513 J. Baker & D. Farrow (Eds.), *Routledge Handbook of Sport Expertise* (Vol.
514 New York, pp. 282-294): Taylor & Francis.

- 515 Travassos, B., Duarte, R., Vilar, L., Davids, K., & Araújo, D. (2012). Practice task
516 design in team sports: Representativeness enhanced by increasing
517 opportunities for action *Journal of Sports Sciences*, 30(13), 1447-1454.
- 518 Van Der Kamp, J., & Renshaw, I. (2015). Information movement coupling as a
519 hallmark of sports expertise. In J. Baker & D. Farrow (Eds.), *Routledge*
520 *Handbook of Sport Expertise*. London, UK: Routledge.
- 521 Vilar, L., Araújo, D., Davids, K., & Bar-Yam, Y. (2013). Science of winning soccer:
522 emergent pattern-forming dynamics in Association Football. *Journal of*
523 *Systems Science and Complexity*, 26, 73-84.
- 524 Vilar, L., Araújo, D., Davids, K., & Button, C. (2012). The role of ecological
525 dynamics in analysing performance in team sports. *Sports Medicine*, 42(1), 1-
526 10.
- 527 Ward-Smith, A. J. (1985). The Influence on Long Jump Performance of the
528 Aerodynamic Drag Experienced During the Approach and Aerial Phases.
529 *Journal of Biomechanical Engineering*, 107(4), 336-340.
530 doi:10.1115/1.3138566.
- 531 Warren, W. H. (2006). The dynamics of perception and action. *Psychological*
532 *Review*, 113(2), 358-389. doi:10.1037/0033-295X.113.2.358.

534 Table 1. Competition variables and definitions

<i>Competition Variables</i>	<i>Constraint Classification</i>	<i>Definition</i>
Round	Task	Each competition consists of six rounds
Wind	Environment	Measured in metres per second. Readings must be under 2 metres per second for jump to be valid for team selection and records
Competition ID	Environment	Three competitions used for analysis (1) Diamond League or DL (2) World Championships or WC and (3) Olympic Games or OG
Previous round foul	Individual	Previous round was classified as a foul
Round 1 foul	Individual	Round 1 jump was classified as a foul
Distance of round 1 jump	Individual	Round 1 jump distance measured in metres
Medal position after previous round	Individual	Athlete enters round in either 1 st , 2 nd or 3 rd position
Top 8 previous round	Individual	Athlete is in a Top 8 position entering the round. After the completion of Round 3, athletes in the top 8 positions are permitted 3 more jumps
Previous round jump distance	Individual	Previous round jump distance measured in metres

535 Table 2. Jump distance and classification – men and women

	Total jumps analysed	Jump Distance		Jump Classification	
		Mean (\pm S.D.)	Median (IQR)	Legal (%)	Foul (%)
Male	2783	7.81 (\pm 0.40)	7.88m (0.34)	1937 (69.90%)	846 (30.40%)
Female	2607	6.48 (\pm 0.35)	6.52 (0.33)	1846 (70.81%)	761 (29.19%)

536 Table 3. Jump distance and classification by round – men and women

<i>Round</i>	<i>Men's Competitions</i>				<i>Women's Competitions</i>			
	Total Jumps Analysed	Jump Distance (m)	Jump Classification		Total Jumps Analysed	Jump Distance (m)	Jump Classification	
		Mean	Legal	Foul		Mean	Legal	Foul
		(±S.D.)	(%)	(%)		(±S.D.)	(%)	(%)
<i>1</i>	559	7.73 (± 0.44)	406 (72.63%)	153 (27.37%)	509	6.45 (± 0.33)	381 (74.85%)	128 (25.15%)
<i>2</i>	557	7.83 (± 0.37)	378 (67.86%)	179 (32.14%)	506	6.49 (± 0.30)	355 (70.16%)	151 (29.84%)
<i>3</i>	543	7.83 (± 0.39)	383 (70.53%)	160 (29.47%)	501	6.47 (± 0.35)	373 (74.45%)	128 (25.55%)
<i>4</i>	380	7.87 (± 0.35)	269 (70.79%)	111 (29.21%)	374	6.50 (± 0.34)	247 (66.04%)	127 (33.96%)
<i>5</i>	369	7.82 (± 0.46)	252 (68.29%)	117 (31.71%)	361	6.49 (± 0.41)	234 (64.82%)	127 (35.18%)
<i>6</i>	375	7.85 (± 0.41)	249 (66.40%)	126 (33.60%)	356	6.49 (± 0.39)	256 (71.91%)	100 (28.09%)

537 Table 4. Jump distance and classification by competition – men and women

<i>Competition</i>	<i>Men's Competitions</i>					<i>Women's Competitions</i>				
	Total Jumps Analysed	Jump Distance (m)		Jump Classification		Total Jumps Analysed	Jump Distance (m)		Jump Classification	
		Mean (±S.D.)	Median	Legal (%)	Foul (%)		Mean (±S.D.)	Median	Legal (%)	Foul (%)
<i>Diamond League</i>	1901	7.78 (± 0.35)	7.82	1337 (70.33%)	564 (29.67%)	1833	6.44 (± 0.35)	6.48	1331 (72.61%)	502 (27.39%)
<i>World Championships</i>	586	7.83 (± 0.37)	7.99	393 (67.07%)	193 (32.93%)	477	6.57 (± 0.30)	6.60	324 (67.92%)	153 (32.08%)
<i>Olympic Games</i>	296	7.83 (± 0.39)	8.03	207 (69.93%)	89 (30.07%)	297	6.62 (± 0.38)	6.67	191 (64.31%)	106 (35.69%)