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Exploring the influence of task and environmental constraints on batting and bowling performance in cricket: A systematic review

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Abstract

Cricket is an unique international sport where environmental and task constraints have shown to have a significant impact on batting and bowling performance. The aim of this systematic review was to determine the effect of task and environmental constraints on cricket performance. A systematic literature search was conducted across Scopus, PubMed, Web of Science, CINAHL, and SportDiscus. Studies were deemed eligible if they reported the effects of pitch type, pitch length, equipment (e.g. cricket bat, batting pads, ball type, etc.) on cricket performance. A total of 20 studies met the inclusion criteria with Kmet score ranging between 75% and 92%. The results from this study demonstrate that environmental constraints such as pitch-type and task constraints such as equipment modification (e.g. type of cricket bat, batting pads, ball) and pitch length can influence cricketer's batting and bowling performance. Scaling cricket bats and reducing pitch length were acutely beneficial to cricket batting, while ball type, pitch length and soil properties were impactful on bowling performance. Importantly though, the impact of constraint manipulation seemed to be influenced by the skill level of the performer. The findings from this study may help to inform coaches and practitioners improve skill acquisition, through constraint manipulation, to develop highly adaptive cricket batting and bowling skill.

Keywords

Coaching, constraints-led approach, skill acquisition, sports equipment, talent development

Introduction

Cricket is an international sport played between two teams, with each team provided an opportunity to bat and bowl. The aim of the bowlers is to restrict the number of runs scored by the opposition team and 'dismiss' the batter, while the batsmen try to score as many runs as possible before or without being dismissed. Unlike most team sports, cricket can be played across three different formats including multi-day match format, One Day Internationals played over one day (50 overs), and the Twenty-Twenty format played over 20 overs. There are various bi-lateral and international tournaments conducted by the cricket playing nations in their respective countries, requiring national level teams to routinely travel to foreign countries and play on unfamiliar pitch conditions and using different types of cricket balls, depending on the host country. As a result, players are required to adapt to a variety of different environmental conditions depending on the match format, venue, and location of the match, which can subsequently influence performance.[1]

Recently, a theoretical framework has risen to prominence which views skill development as an emergent process based on an interaction between individual, task, and environmental constraints.[2,3] Individual constraints

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are physical or psychological factors of an individual that influences their respective physical attributes,[4–6] and motivation or mental toughness.[7] Following the pedological constraints led approach to skill acquisition, task constraints refer to the characteristics of the task itself that may shape the way a person performs a skill.[8,9] Factors such as the equipment used or task relevant goals are encompassed under this particular category of task constraints and in turn, are thought to influence the way an individual learns and performs a skill. Alternatively, environmental constraints refer to the external physical factors in the environment that shape how an individual performs a skill.[2] Examples of physical environmental constraints may include factors such as the layout of the space in which the skill is being performed (e.g. backyard, open field), surface properties (e.g. dry, wet) or ambient atmosphere. Together, these constraints interact to shape emergent behaviour.[10,11]

There is a growing body of empirical work which has applied this theoretical framework to investigate how coaches and practitioners can manipulate task and environmental constraints to create highly effective and representative practice.[12–14] Modifying constraints during practice has been proposed as a means to encourage individuals to explore diverse movement solutions and adapt their motor behaviour to meet the demands of the task and environment. This idea aligns with the dynamic systems theory, which posits that motor behaviour arises from the interaction between multiple systems, including individual, task, and environmental constraints, and skill emerges through self-organization rather than a hierarchical process.[15] To assess the functionality of the stable movement pattern that emerges, researchers may evaluate performance production, which involves examining the execution of the motor skill itself, or performance outcome, which involves a more comprehensive assessment of whether the motor skill achieved the desired goal under the given task and environmental constraints. For example, research measuring the performance outcomes of cricket batting have included the number of runs scored against an opposition, number of shots played off front foot,[16] while performance outcome measures for cricket bowling have included bowling speed or accuracy during a game/training situation.[17] Collating the findings on the impact of manipulating task and environmental constraints on performance outcome measures could be highly valuable for coaches, by providing an evidence-base for using key constraints in practice to optimise skill development. Therefore, the primary aim of this review was to systematically and critically evaluate studies that have examined the role of task and environmental constraints on cricket performance. The rationale of this review to focus on task and environmental constraints was grounded in practical applicability for coaches to source current evidence, regarding the various types of constraints that could be manipulated during practice. Thus, a systematic review on this topic will be useful for coaches in identifying constraints that contributes to performance optimisation and athlete preparation. Furthermore, such a review will highlight the methodological difficulties identified by previous studies to provide recommendations for future research.

Methods

Experimental approach to the problem

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[18]

Inclusion/exclusion criteria

Studies were deemed eligible to be included in this review based on the following criteria: (a) studies that described the influence of environmental and task constraints such as: pitch type, pitch length, and equipment (e.g. cricket bat, batting pads, ball type, etc.) on cricket performance; (b) studies that were of original research; (c) studies that reported any measure of bowling performance measures such as (but not limited to) ball speed, swing, or rebound velocity; and (d) studies that reported any measure of batting performance such as (but not limited to) number of runs, time to complete a run. Studies were excluded if: (a) studies did not report findings pertaining to task or environmental constraints and cricket performance; (b) conference, poster presentations, or case studies; (c) studies that reported outcomes other than batting/bowling performance (for example, movement pattern of the batsmen/bowler in response to changing task or environmental constraints); and (d) studies that were not related to cricket.

Methodology for literature search

A literature search was conducted across PubMed, Scopus, SportDiscus, Web of Science, and CINAHL to extract abstracts for relevant papers on batting and bowling performances. For PubMed search, the following MeSH terms were used in combination: (Humans or Young Adult or Adolescent) and (Biomechanical Phenomena or Muscle Strength or Muscle, Skeletal or Sports or Task Performance and Analysis or Time and Motion Studies or Motor Skills). This string of mesh terms was then combined with the following free text: Bowling or Bowler* or Cricket or Bat or Batsmen or Batsman, and separately applied for search in Scopus, SPORTDiscus, Web of Science, and CINAHL. Apart from the aforementioned search strategy, a grey search was also performed through Google Scholar and the references of the included studies.

Selection procedure

Following the literature search based on keywords, an independent researcher (KD) conducted the stepwise search across all the required studies on the 14th Feb, 2022. The abstracts were then imputed into a bibliography software (Endnote, Clarivate Analytics, Philadelphia) to remove duplicate studies, and then an abstract list was extracted to Microsoft Word. Two authors (US and AR) screened the first 300 abstracts from the abstract list together to optimise inter-rater reliability of the inclusion criteria, as either 'meeting the inclusion criteria', 'maybe', or 'not meeting the inclusion criteria'. The two authors (US and AR) then independently screened the rest of the abstract list independently, with an inter-rater reliability of 0.83 (95% confidence interval: 0.66–0.99) based on the weighted Kappa statistic. Following screening of abstracts, full text articles were retrieved from the major data bases. Any discrepancies that were raised between the abstract screeners were discussed and resolved in a consensus meeting. If there was still a disagreement, further discussion took place with the other two authors (KD and JC) and then a decision regarding the inclusion/exclusion of the papers was finalised.

Data extraction

Upon retrieval of the full text articles, data pertaining to methodological design, participant information (age, body mass, height, experience), aims, outcome measures and main findings were extracted from each study. For the studies in which only bowling machine and cricket bats were used instead of human participants, the characteristics of the bowling machine and cricket bat were reported.

Risk of bias

The methodological quality of each study was critically examined using the assessment checklist proposed by Kmet.[19] According to the Kmet tool for the quantitative analyses, the quality of studies was typically assessed using 14 questions pertaining to the risk of bias of randomised controlled trials. The three questions regarding confounders for randomisation and blinding procedures were excluded from the Kmet tool, given that the studies included in the current systematic review were either a single-group repeated measures or quasi-experimental designs.[17] To better align the Kmet items with the methodological nature of the included studies, the three questions on randomisation and blinding procedures were replaced with two questions, including: (a) whether the task specific instructions were provided to bowlers/batsman to determine the ecological validity of the study; and (b) whether the studies mentioned the type of conditions, such as ball type, pitch type, etc. To ensure reliability of the amended Kmet scoring method, two authors (US and AR) independently assessed the quality of the studies, with scores of 0—not meeting the criterion; 1—partially meeting the criterion; or 2—completely meeting the criterion. The total score was then divided by the maximum total score (24), resulting in the quality scores for the studies. The Kmet scores of <50%, 50%–66%, 67%–83%, and >84% were considered as poor, fair, good, and excellent, respectively.

Results

Literature search

A detailed outline for each step of the literature search has been provided in Figure 1. A total of 4440 (1427 from PubMed; 482 from CINAHL; 884 from Scopus; 787 from SportDiscus; 858 from Web of Science; 2 from additional Google Scholar search) abstracts were initially identified and screened based on the inclusion criteria from SportDiscus, CINAHL, Scopus, PubMed, and Web of Science. Following the removal of duplicates, 2536 abstracts were excluded and 51 full text articles were included. These full-text articles were then further screened with 20 original articles included for the review. All the included studies reported environmental constraints related to batting and bowling performance outcomes.

Participant characteristics

The characteristics and outcomes of the twenty studies included in this review are described in Table 1 and Table 2. The total number of participants was 644 and their mean age ranged between 5 and 24 years. Five of the included studies were without human participants wherein cricket bats (fixed to a suitable apparatus) were used in two of the studies,[20,21] while three studies used bowling machines.[22–24] The characteristics of the nature of participants included in our review have been summarised in Table 1.

Study characteristics

Of the twenty included studies, six studies examined the effects of environmental constraints and remaining fourteen studies examined task constraints. Specifically, four studies reported the effect of pitch length on bowling and batting performance, and these studies reported parameters such as bowling speed, bowling accuracy, runs and number of shots in different areas as performance metrics.[16,28–30] Ten studies reported the effect of equipment, namely batting pads, ball type and bats on cricketer's performance and these studies reported performance parameters such as three runs time, runs (boundaries), rebound characteristics of the ball, bowling speed and accuracy.[10,20,21,27,31,33–37] The remaining six studies investigated the effect of pitch type on bowling performance.[22–25,32,38] The summary of findings of the included studies has been provided in Table 2.

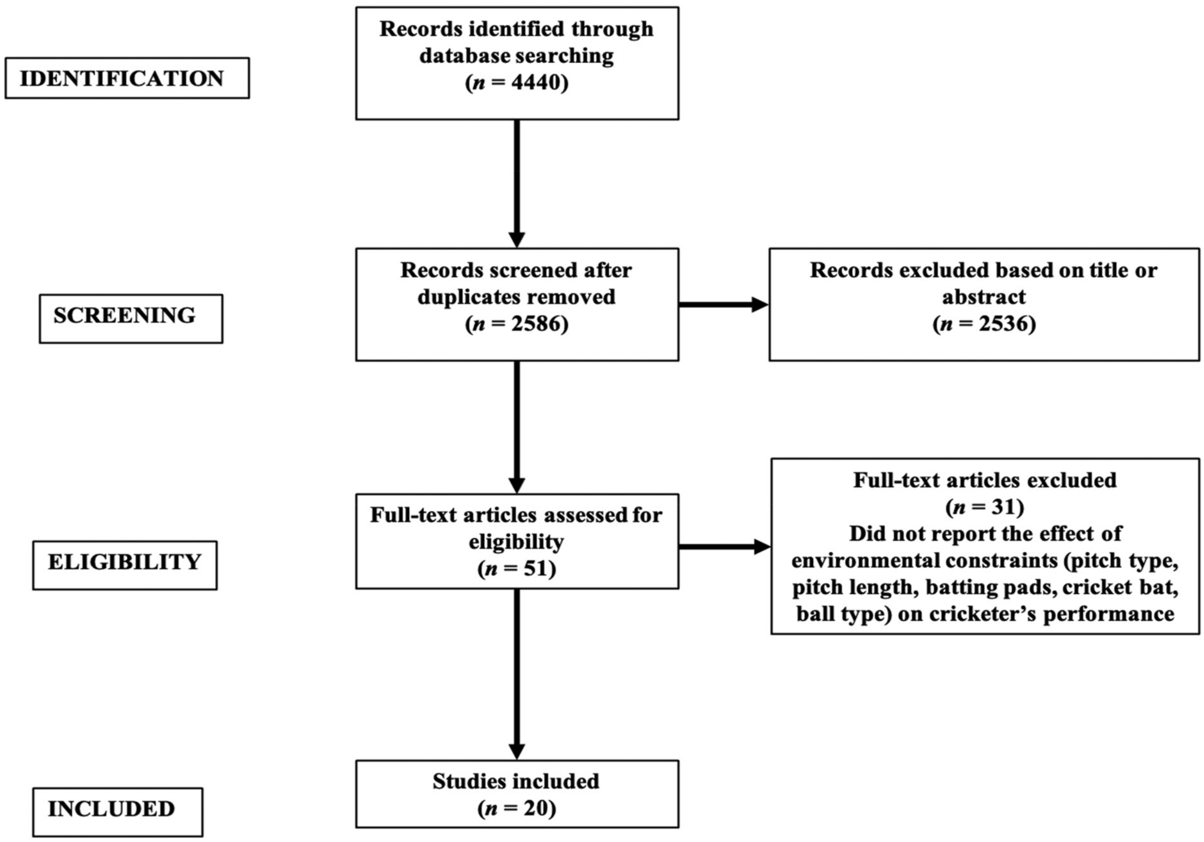

Figure 1. PRISMA flowchart for search strategy.

Quality assessment of included studies

Table 3 depicts the quality score of all the included studies with the mean quality assessment score of 84%, ranging between 75% and 92%. A total of eleven studies were rated as excellent quality and remaining nine were of good quality. Most studies received a score of 'zero' for neither mentioning the number of trials nor the sample size calculation. All the included studies met the criteria for the following: sufficient description of objective; reporting on method of subject selection; appropriate outcome measures; type of analysis performed; estimate in variance; description of the instructions provided to bowlers or batsmen for performing the particular task; reporting results in sufficient detail; and discussion of results in supporting the conclusions. The least reported criteria included the following: study design; experience of the batsmen/bowlers who participated in the study; sample size calculation and the all the conditions (pitch type, ball type and weather) in which the study was performed.

Discussion

The aim of the current systematic review was to investigate the effects of task and environmental constraint manipulation on cricket batting and bowling performance. Based on the inclusion criteria, 20 studies were included in our review. The Kmet scores ranged from 75% to 92%. There were several task and environmental constraints that resulted in a significant change to batting or bowling performance. Specifically, task constraints such as equipment modifications (i.e. composition of the bat, scaling of bat, ball type, and batting pads), and pitch length have been shown to change batting performance metrics. With regards to the bowling performance, task constraints such as modifying the pitch length, and ball weight, and environmental constraints such as pitch type, have demonstrated a considerable impact on bowling performance. The following sections discuss the influence of various task and environmental constraints manipulation on cricket batting and bowling performance.

Batting performance

The constraints manipulated across studies on batting performance included only task constraints, such as equipment modifications (i.e. composition of the bat, scaling of bat, ball type and batting pads), and pitch length.

Task constraints. A small number of studies have been conducted on the effects of different types of bats on acute batting performance metrics. For instance, differences in rebound speeds (i.e. speed of the ball off the bat) were

Table 1. Study characteristics of the included studies.

Study	Nature of Participants	Gender	Sample Size	Characteristics	Skill level
Ball et al.[23]	Bowling machine	NA	160–180 deliveries for each pitch	A JUGS cricket bowling machine (Jugs Sports, Oregon)	NA
Carre et al.[24]	Bowling machine	NA	360 impact images a day, 1440 per trial	A JUGS cricket bowling machine	NA
Connor et al.[10]	Humans	NR	43 Cricket Players	NR	Specialist batters played during 2016/17 and 2017/18 Australian Sheffield shield seasons
Crowther et al.[25]	Humans	Male	25 Spin Bowlers: 12 Australian Spin Bowlers 13 Indian Spin Bowlers	Australian Bowlers Age: 28.0 ± 3.7 years Indian Bowlers: Age: 29.1 ± 4.1 years	Indian and Australian players played each other from December 2007 to January 2015.
Crowther et al.[22]	Bowling machine	NA	276 Spin Deliveries: 139 wrist spin, 137 finger spin	A Merlyn by BOLA (Manufactured by Stuart and Williams) Spin Bowling Machine	-
Crowther et al.[26]	Humans	NR	8 Spin bowlers	Age: 21 ± 3 years	Started playing cricket formally at the age of 8 ± 2 years
Dancy and Murphy[27]	Humans	Male and Female	43 Children: 29 Boys 14 Girls	Boys and Girls Age: 5.2 ± 0.8 years	The children had little or no experience of playing cricket in a formalised programme.
Elliot and Ackland[21]	Bat: Suspended pneumatically; Ball: Bowling machine	NA	10 bats (2 Senior Aluminium, 3 Senior Wooden, 1 Junior Aluminium, 4 Junior Wooden)	NR	NA
Elliott et al.[28]	Humans	NR	37 Fast Bowlers: 14 Under-11 Fast Bowlers 11 Under-13 Fast Bowlers 12 Under-15 Fast Bowlers	Under-11 Fast Bowlers Mean age: 10.6 years Under-13 Fast Bowlers Mean Age: 12.5 years Under-15 Fast Bowlers Mean age: 14.7 years	Competed in the under-11, under-13, or under-15 junior age groups, and were identified as fast bowlers by their respective coaches in the 2002–03 season.
Harwood et al.[29]	Humans	Male	20 Male Junior Right-Arm Seam Bowlers	Age: 10.8 ± 0.63 years Height: 1.46 ± 0.058 m	Identified by their county or club coaches as being the best in their age group squads.
Harwood et al.[16]	Humans	Male	308 Under-10 and Under 11 Players (Club 20-yards: 92; Club 16-yards: 98; County 19-yards: 61; County-16-yards: 57	Age: - Club 20-yards:0.41 ± 0.98 years; Club 16-yards: 10.46 ± 0.95 years; County 19-yards: 10.08 ± 0.53 years; County 16-yards: 10.15 ± 0.50 years	Under-10 and Under-11 boys from English County Cricket Board.

(continued)

Table 1. (continued)

Study	Nature of Participants	Gender	Sample Size	Characteristics	Skill level
Harwood et al.[30]	Humans	Male	308 Under-10 and Under 11 players (Club 20-yards: 92; Club 16-yards: 98; County 19-yards: 61; County-16-yards: 57	Age: - Club 20-yards: 0.41 ± 0.98 years; Club 16-yards: 10.46 ± 0.95 years; County 19-yards: 10.08 ± 0.53 years; County 16-yards: 10.15 ± 0.50 years	Under-10 and Under-11 boys from English County Cricket Board.
Headrick et al.[31]	Humans	Male	11 Skilled male cricketers	Age: 16.6 ± 0.3 years	Playing experience: 7.5 ± 0.5 years
James et al.[32]	Humans	NR	82 Professional cricketers	NR	NR
Loock et al.[33]	Humans	NR	15 Young elite cricket players	NR	Cricket players were attending the Lennon Eastern Province Cricket Academy (South Africa) and out of these, 4 players had represented Eastern Province in senior provincial cricket
Noorbai et al.[34]	Humans	Male	12 Junior male cricketers	Age: 9–10 years	NR
Petersen et al.[35]	Humans	Male	20 Male fast bowlers	Age: 22 ± 3 years,	Senior club cricket players
Stretch et al.[20]	Bat: Affixed to a testing rig; Ball: Projected using compressed air	NA	2 Composite bats 4 Wooden bats 18 Deliveries for each bat at three speeds	Composite bats Mass: 1.25 ± 0.07 kg Wooden bats Mass: 1.38 ± 0.05 kg	NA
Webster et al.[36]	Humans	Male	10 Male cricketers	Age: 19 ± 0.8 years	All players were playing for their county first or second team.
Wickington and Linthrone[37]	Humans	Male	10 Male fast-medium pace bowlers	Age: 24 ± 5 years; Height, 1.80 ± 0.06 m; Mass: 90 ± 8 kg	Cricket at club or county level cricketers

NA: not applicable; NR: not reported.

Table 2. Description of task and environmental constraints and results reported in the included studies.

Study	Task/ Environmental Constraint	Characteristics of Environmental Constraint	Outcome Measures	Results
Task Constraint				
Connor et al.[10]	Equipment	Kookaburra and Duke ball	Batting performance	No significant interactions were found between innings and ball type for average runs scored. No interaction was reported between wicket taken by bowler, ball and innings.
Dancy and Murphy[27]	Equipment	Regular Bat/Modified Bat and Regular Ball/Modified Ball	Performance score (Batting)	Compared to the regular scaled-ball, modified ball demonstrated significant and higher batting performance measured as shots played through target areas
Elliot and Ackland[21]	Equipment	Wooden and aluminium bat	Rebound coefficient	The wooden bat with similar physical attributes demonstrated superior impact characteristics compared to the aluminium bats.
Elliott et al.[28]	Pitch length	Pitch length: 20.12 m, 18 m, 16 m	Bowling accuracy	Significant difference in accuracy between 20.12 m and 16 m pitch length for under 11, under 13 and under 15 bowlers. Furthermore, significant difference in accuracy between 18 m and 20.12 m pitch length for under 15 bowlers.
Harwood et al.[29]	Pitch length	16 yards and 19 yards pitch	Bowling speed and accuracy	Junior bowlers adjusted projection angle (lower) of the ball without significant change in ball speed or release position on a 16-yard pitch. On shorter pitch, players bowled with a more downward trajectory as observed in elite adult players.
Harwood et al.[16]	Pitch length	16 yards, 19 yards and 20 yards pitches	Bowling, batting and fielding	Number of playable deliveries increased and the number of wide balls reduced on a 16 yards pitch in club Under-11 matches. Increase in the amount of running activities by batters on a 16 yards pitch in both club and county matches. Number of shots to the mid-wicket area decreased on a 16 yards pitch in both club and county matches.
Harwood et al.[30]	Pitch length	16 yards, 19 yards and 20 yards pitches	Batting performance	Club under-11 and county under-10 showed that when playing batters played more back foot shots to short balls on a 16-yard pitch. County batters played more front foot shots to full balls compared with matches on the currently recommended 20- or 19-yard pitches.
Headrick et al.[31]	Equipment	Bats with different mass and MOI characteristics	Batting performance	Bats with greater mass and MOI were found to return slower swing velocities whereas bats with the

(continued)

Table 2. (continued)

Study	Task/ Environmental Constraint	Characteristics of Environmental Constraint	Outcome Measures	Results
				smallest mass and MOI produced the shortest step length, along with the fastest maximum velocity.
Loock et al.[33]	Equipment	Traditional Pad, Molded Pad, Light-weight Pad	Running between the wickets time	No significant differences between the types of batting pads and time to complete the three-run test and the turning time.
Noorbai et al.[34]	Equipment	Coaching cricket bat (weight, 575 g)	Batting performance	Additional 100 runs were scored when using the coaching cricket bat compared with a conventional cricket bat. Experimental group showed improvement in performance 6 weeks postintervention (training with the coaching cricket bat).
Petersen et al.[35]	Modified-ball training	133–179 g cricket balls	Bowling performance	Trivial/small changes in ball speed and accuracy.
Stretch et al.[20]	Equipment	Composite and wooden bats	Ball rebound velocities (Batting)	Composite bats showed significantly smaller rebound speeds and coefficient of restitution compared to traditional bats.
Webster et al.[36]	Equipment	Batting pads: - Pad 1: Compromise between the two extremes, and consisted of multiple foams; Pad 2: Modern pad design, constructed of a single piece of molded closed-cell polyethylene foam; Pad 3: Traditional construction of pad, comprising multiple foams and pieces of cane for added support	Running between the wickets time (Batting)	Pad 3 resulted in significantly slower times than Pad 1 and Pad 2.
Wickington and Linthrone[37]	Equipment	Modified balls (71, 113, 142, 198, and 213 g)	Bowling speed, accuracy and mechanics	Ball speed decreased at a rate of about 1.1 m/s per 100 g increase in ball weight. Accuracy and bowling mechanics were not adversely affected by changes in ball weight
Environmental Constraint				
Ball et al.[23]	Pitch type	Traditional: Synthetic pitch (Lords, Caulfield East, Melbourne) with 17 mm pile height and polyethylene synthetic grass laid on a concrete surface. All-Seasons: Synthetic pitch (Mackie Reserve, Carnegie, Melbourne) with medium pile height and polyethylene synthetic grass surface laid on a rubber shock pad fitted onto a concrete slab.	Ball speed and ratios of ball speed and angle	The All-Seasons synthetic surface had a lower speed ratio and a higher angle ratio than the Traditional synthetic surface. Speed ratio for the Traditional surface was within the range reported for natural turf but the value for the All-Seasons surface was outside the range. Both synthetic surfaces produced angle ratios greater than those for natural turf surfaces.

(continued)

Table 2. (continued)

Study	Task/ Environmental Constraint	Characteristics of Environmental Constraint	Outcome Measures	Results
Carre et al.[24]	Pitch type	JUGS Professional bowling machine was used. Balls were fired at an average speed of 32 m/s, at 14° to the horizontal and with 54 rad/s of back spin.	Rebound velocity	Damp, soft pitch were found to have a lower rebound velocity with high top spin, whereas a firm, dry pitch had a higher rebound velocity with low top spin.
Crowther et al.[25]	Pitch type (Home and Away)	Indian and Australian Pitch	Bowling speed (Bowling)	Compared to Australian bowlers, Indian bowlers produced faster mean delivery speed in four matches and slower bowling speed in another four matches in home conditions. Furthermore, the home team bowlers showed greater variability in delivery speed compared to the away bowlers. In Australia, the home bowlers showed less variability in delivery speed compared to the away team.
Crowther et al.[22]	Pitch type	Bespoke international pitch (BIP; higher sand content at 43.28%) and Common Australian pitch (CAP; lower sand content at 7.44%)	Ball pace, bounce and deviation (Bowling)	Reflection pace was significantly lower in both the pitches when seam impacted the pitch, compared to when it did not. No significant differences in reflection bounce for both the pitches when seam impacted with the pitch, compared to when it did not. Reflection deviation was significantly larger for both the pitches when seam contacted the pitch during the impact, compared to when it did not.
Crowther et al.[26]	Pitch type and ground dimensions	Familiar and unfamiliar pitch	Bowling performance	The bowlers playing on a familiar pitch reported attuning to task constraints (75%). However, when bowling on the unfamiliar pitch, bowler's attention was more focused upon picking up key affordances pertaining to environmental pitch constraints (100%). Furthermore, most of the bowlers bowled differently on the unfamiliar pitch by using more 'side-spin' and less 'over-spin'.
James et al.[32]	Pitch type	Different county pitches	Bowling performance	The pace of the cricket pitches were correlated with their relative soil properties and a high clay content pitch was associated with slow pace rating whereas low clay content pitches were associated with a fast pace rating. Also, pace seems to be negatively correlated with moisture content.

Table 3. Quality assessment scores for the included studies.

Author	1	2	3	4	5	6	7	8	9	10	11	12	Score (%)
Ball et al.[23]	2	1	2	2	2	1	1	2	2	2	2	2	88 (Excellent)
Carre et al.[24]	2	1	2	2	2	0	2	2	2	2	1	2	83 (Good)
Connor et al.[10]	2	1	2	1	2	0	2	2	2	2	2	1	79 (Good)
Crowther et al.[25]	2	2	2	1	2	0	2	2	2	2	2	2	88 (Excellent)
Crowther et al.[22]	2	1	2	2	2	1	2	2	2	2	2	2	92 (Excellent)
Crowther et al.[26]	2	1	2	1	2	0	2	2	2	2	2	2	83 (Good)
Dancy and Murphy[27]	2	1	2	1	2	2	2	2	2	2	2	2	92 (Excellent)
Elliot and Ackland[21]	2	1	2	1	2	NA	2	2	2	2	NA	NA	88 (Excellent)
Elliott et al.[28]	2	1	2	1	2	0	2	2	2	2	2	2	84 (Excellent)
Harwood et al.[29]	2	1	2	1	2	0	2	2	2	2	2	2	84 (Excellent)
Harwood et al.[16]	2	1	2	1	2	0	2	2	2	2	2	1	79 (Good)
Harwood et al.[30]	2	1	2	2	2	0	2	2	2	2	2	2	88 (Excellent)
Headrick et al.[31]	2	1	2	2	2	0	2	2	2	2	2	2	88 (Excellent)
James et al.[32]	2	1	2	1	2	0	2	2	2	2	2	2	83 (Good)
Loock et al.[33]	2	1	2	0	2	0	2	2	2	1	2	2	75 (Good)
Noorbai et al.[34]	2	2	2	2	2	0	2	2	2	2	2	1	88 (Excellent)
Petersen et al.[35]	2	1	2	1	2	0	2	2	2	2	2	2	83 (Good)
Stretch et al.[20]	2	1	2	2	2	0	2	2	2	2	2	2	88 (Excellent)
Webster et al.[36]	2	1	2	1	2	0	2	2	2	2	2	1	79 (Good)
Wickington and Linthrone[37]	2	1	2	2	2	0	2	2	2	2	2	1	83 (Good)

NA: not applicable.

reported between wooden and composite bats, where wooden bats were found to have higher post impact speed of the ball compared to composite bats.[20] In addition, rebound characteristics differed between wooden bats and aluminium bats,[21] indicating that the choice of a bat with suitable material may augment batting performance during practice. Another study aimed to examine how the mechanical properties of the bat influenced highly skilled youth participants to perform a front foot straight drive.[31] The results from this study revealed that when blindfolding the participants, the first-choice bats were the two bats with the smallest mass and moment of inertia values, being preferred by almost two thirds (63.7%) of the participants. When participants were presented with six bats in random order (different from the blindfolded condition) to perform front foot straight drives, it was found that bat velocity, step length, and bat–ball contact position measures significantly differed between the bats.[31] These results suggest that the physical properties of the cricket bats affect the perceptual preference of skilled youth participants, at the control stage of learning, to regulate batting actions.

Scaled equipment has also been reported to have a positive learning effect on batting performance. For instance, a study by Noorbai and colleagues[34] used a novel cricket bat to determine its effectiveness on enhancing the batting performance and technical parameters (i.e. direction of backlift) in junior batsmen. Using this novel, lighter bat, it was reported that batsmen scored an additional 100 runs during a modified training game compared to using a conventional cricket bat. In addition, post 6 weeks training intervention with the novel bat resulted in improved performance during a modified training game and increased lateral backlift, which the authors argued may facilitate more effective ball striking.[34] Apart from scaling of the cricket bat, modified balls have also been used as a coaching technique for the enhancement of batting skill. For example, the performance score (i.e. points based on the scoring zones) were reported to be significantly higher with the modified ball (modified tennis ball with circumference 42 cm), as compared to the regular ball (compressed tennis ball with circumference 20.8 cm) and regular cricket bat for children with little or no experience of playing cricket in a formalised programme.[27] One potential explanation could be due to the increased circumference of the ball, which may have simplified the striking task.[27] Similar results have also been observed in youth tennis athletes, where modified tennis balls (lower compression) with reduced dimensions, mass and coefficient of restitution resulted in a more favourable bounce as compared to the standard ball which provides less time for a racket-ball impact.[39,40] Therefore, task modification should be encouraged in order to bring about the practice of a behaviour under representative conditions. Future research and practice should also consider the optimal 'challenge point' for learners, to guide the appropriate level of equipment modification to develop greater perceptual-motor and cognitive skills in junior cricketers.

Another constraint manipulation adopted by researchers to investigate perceptual-motor skill performance involved the manipulation of pitch length, which in turn influences the temporal demands on the batter. A study by Harwood et al.[16] examined the batting performance of club and county junior cricketers on 16-, 19-, and 20-yard pitches and found that playing on a shorter pitch resulted in changes to batting performance metrics such as number of shots played across the mid-wicket, covers and the number of boundaries. It was concluded that a shorter pitch reduces the availability of ball flight information for the batsmen, thus increasing the temporal demands and forcing a change in movement strategy (e.g. faster movement timings or shorter movements). Therefore, by increasing the temporal demands of the task, batters are required to rely more so on earlier perceptual information which, when appropriately periodised, may aid the development of their anticipatory skill. Adopting shorter pitch lengths as part of a periodised (i.e. systematic) practice approach may aid skill development benefit for the batsmen.[41] However, it should be noted that the temporal demands of the task must not exceed the capacity of the learner,[42] highlighting the importance of future research into optimal challenge points for skill development, as well as longitudinal studies looking at the learning effect of constraint manipulation.

The studies in the current systematic review did, however, find that not all task constraints manipulations affected batting performance. For instance, there was no difference in running between the wickets times when batters wore three different types of batting pads.[33] However, one study did report differences in sprint time between different types of pads.[36] The disparity in these findings reported could be due to the variation in weight and dimension of the batting pads used in both the studies, which in turn could have affected running time; though further research is required to determine whether the design of batting pads could potentially impart better running time. The use of different ball types (Kookaburra and Duke) on state level cricketers was also reported to have little impact on batting performance. The performance parameters that were taken into account included runs scored, boundaries, and strike rate during professional domestic level matches.[10] Even though both Kookaburra™ and Duke™ balls have different swing properties, Duke™ balls have a greater propensity to 'swing' (deviate laterally through the air) for longer periods,[10,43] their effect on batting performance was negligible. However, these findings may also be due to the high skill level of state level cricket batters, and the performance metrics analysed not being sensitive enough to detect changes at this level of competition.[10] It may be that the influence of task constraints on behaviour and performance becomes less impactful for more skilled athletes, however, further work in this area is required to examine the impact on junior cricketers.

Bowling performance

The manipulation of environmental constraints such as pitch type, and task constraints such as pitch length and ball weight were found to have a considerable impact on bowling performance.

Task constraints. A number of studies have shown that reducing pitch length reportedly improves bowling accuracy, while ball release speed remains the same.[16,28,29] Authors in these studies have suggested that, based on their findings, shorter pitch lengths may be more appropriate for junior cricketers' development. This could be attributed to their developing anthropometric and physical characteristics, which in turn influences bowling skill development.[28] It is worth noting that these studies were acute, therefore further research is required to determine the long-term effects of shorter pitch length on bowling skill development.

Whilst evidence for pitch length affecting cricket skill performance is congruous, the literature on weighted and unweighted ball have revealed an equivocal impact the bowling performance measures.[35,37,44] Two studies reported the effects of modified ball weight training on bowling performance measures such as bowling speed and accuracy.[35,37] For example, Petersen and colleagues[35] conducted a 10-week intervention study in which the participants from a cricket club were divided into traditional training group and modified implement training group. The traditional training group used only regulation cricket balls (156 g) and the latter group used a combination of overweight (161–181 g), underweight (151–131 g), and regulation cricket balls. The modified-implement training group showed greater improvement in speed and substantial loss in bowling accuracy than the traditionally trained group over the 10-week training period. The authors concluded by stating that such a method might not be beneficial for club cricketers and further research is required for recommending such training practices.[35] In another study,[37] meaningful increase in bowling speed was observed in two out of five players assigned to the modified-implement training group. A recent meta-analysis also reported that modified ball weight training had a moderate effect on bowling speed, albeit the findings being non-significant.[45] The reasons for the non-significant findings were at least partially attributed towards the difference in physical training background, skill level of the participants, and duration of the training program. With regards to the effects of modified ball weight training on bowling accuracy, the studies included in this systematic review reported contrasting results. For instance, Petersen et al.[35] reported a 7% decline in bowling accuracy post 10 weeks of modified implement training with balls of 84%−116% of standard mass. Contrarily, Wickington and Linthrone[37] reported substantial improvement in bowling accuracy post 8 weeks of modified implement training with a ball weight 46%−137% of standard mass. The disparity in findings could be due to the difference in the administration of the testing methods for measuring accuracy. Petersen and colleagues[35] measured bowling accuracy by scoring the delivery 'successful' if the ball was pitched between 6 and 7 m from the stumps and 'unsuccessful' if pitched outside the aforementioned range, whereas Wickington and Linthorne[37] used a points-based scoring system with a vertical target sheet positioned at the batting end in line with the stumps. Therefore, these findings from the included studies suggest that further research is required to determine the effects of modified ball weight training on bowling accuracy.

Environmental constraints. Studies have examined the effects of pitch-type on measures of bowling performance such as ball swing or speed. As an example, a recent study examined the difference in spin bowling delivery speed during test matches played between Australia and India from 2007 to 2015 in both Australian and Indian environments.[25] It was reported that the success of Australia's spin bowlers in their home environment was linked with a lower bowling average and bowling strike rate compared to Indian spin bowlers. There was also less variability in the delivery speed of Australian spin bowlers in 9 of the 11 matches (ratio < 0.83). However, the success of Indian spin bowlers in their home environment was associated with an economy rate that was 1.5 runs lower and a bowling average that was 19.4 runs lower than the Australian bowlers. Indian spin bowlers showed greater variability in delivery speed (ratio > 1.20) in 6 of the 10 matches, which suggest that increased variability might have contributed to the success of Indian spin bowlers in their home conditions. Importantly, this study proposed that neither group significantly changed their bowling tactics according to the opponent's home conditions. This may be due to the difficulty of successfully adapting to foreign conditions, which in turn could have adverse effects on their performance in away conditions. Furthermore, a study aimed to understand the adaptive responses of emerging Australian expert spin bowlers in relation to familiarity towards the pitch in a performance setting.[26] Bowlers competed in three small-sided practice matches with one played on a familiar pitch and two played on an unfamiliar pitch. In the familiar pitch, majority of the bowlers tended to bowl with more 'over-spin' (ball spinning in the same direction as travel) and some 'side-spin'. Overall, the bowlers playing on a familiar pitch mostly reported attuning to task constraints (75%), with the least attention on the pitch or environmental constraints. Whereas, bowling on an unfamiliar pitch, bowler's attention was more focused on picking up key affordances related to environmental pitch constraints (100%), and least attention on task constraints (i.e. the opposing batter's intentions) (37%). Due to the increased attention towards the pitch's characteristics, more than half of the bowlers reported that they bowled differently with more 'side-spin' and less 'over-spin'. However, these findings were reported in cricketers playing at an international level and further research is required to understand the effects of such environmental and task constraints on junior cricketers.

Compounding the challenges of playing in unfamiliar playing conditions, a significant body of work has also reported that the composition of cricket pitches are likely to play a crucial role in pace and bounce characteristics,[23,24,32] which home team players would have greater familiarity towards. Crowther and colleagues[22] compared pace and bounce characteristics on two different pitch-types (traditional Australian pitch and bespoke Indian pitch), and reported significant differences in both bowling measures between the two pitch types. This was further emphasised by a study performed by Connor and colleagues[10] in which significant differences in bowling performance during the first few days of a first-class match (i.e. first innings) and the final days of the match (i.e. second innings) were reported, and suggested that this may be due to deterioration of pitch conditions and increased variability in ball-bounce trajectory off the pitch. However, it is still unclear how bowlers adapt to the pitch conditions, and whether familiarity hastens functional adaptive behaviours and superior performance. Together, these results suggest that skill development training should consider encouraging adaptations to different environmental conditions, and can influence performance in both amateur and elite level cricketers. However, there is still limited evidence on other types of pitch surfaces such as cement, synthetic, or different pitch soils and its impact on skill development in junior cricketers.

Limitations

Our study has a few limitations that need to be highlighted. Firstly, even though studies showed that constraints manipulation can have an impact on cricketer's performance, there is a lack of longitudinal studies investigating the learning effects. Secondly, it should be noted that a significant number of studies included in this review are from western countries, despite cricket being a global game. This may introduce a level of bias and serves to highlight the unknown degree of sociocultural influence this pedagogical approach has on researchers and coaches with differing approaches (e.g. learner-centric or coach-centred). Thirdly, the performance outcomes measures for batting/bowling in response to the individual constraints were heterogenous in nature, with different outcomes reported in each of the included study. This might have introduced some bias in our results and limited the application of our findings.

Conclusion

Constraint manipulation has a profound impact on batting and bowling performance, which could be leveraged by coaches and used to help improve skill acquisition. In particular, scaling the bat, ball or reducing pitch length can be beneficial to cricket batting development, at least in part due to the change in information-movement coupling when batting with, for example, a lighter bat or shorter pitch. Similarly with respect to cricket bowling, reducing pitch length favoured improvement in bowling accuracy. Future research exploring constraint manipulation for skill development should consider examining systematic practice design (i.e. periodised approaches over longer term) and exploring the optimal challenge point for effective skill development.

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