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The effectiveness of constraints-led training on skill development in interceptive sports: A systematic review

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Abstract

There has been a recent increase in constraints-led training to assist the development of technical and cognitive skill in sports. While the benefits of constraints-led training appear obvious, the evidence for this type of training is not clear. Therefore, a systematic review of the literature was conducted to establish the effectiveness of this approach to training within interceptive sports. Four databases (Google Scholar, JURN, Mendeley and Science Direct) were searched for journal articles focused on skill acquisition within interceptive sports. A methodological and reporting quality assessment was done to determine the quality of each article. Eighteen articles were selected for review. The results of these two quality assessments revealed poor quality scores for the majority of the studies. However, 77.7% of the studies found a positive effect in skill acquisition following manipulation in training protocol; therefore, the implementation of the constraints-led approach within interceptive sport can be advocated. Key methodological structures were identified as well as aspects of methodology that should be avoided to ensure reliable results for future studies. Further research is required to determine the effectiveness of constraints-led training on interceptive sporting performance.

Keywords

Ecological dynamics approach, review, skill acquisition, sports science, training

Introduction

Sports scientists and practitioners are constantly striving to improve human performance by optimising physical-, technical- and/or cognitive-based training regimes. Attention has primarily focused on physical training, with research on the technical and cognitive aspects receiving less work.[1] The authors' speculate that this may be due to the more obvious limitations of suboptimal physiological conditioning, commonly seen via injuries and burnouts to athletes, on performance.[1] In contrast, the performance benefits of technical and cognitive research may not be as apparent. Williams and Hodges[1] suggest that this may be due to the relative difficulty of evaluating behavioural changes compared with physiological changes, biomechanical study of technique and skill-related performance tests.

The technical and cognitive aspects of training are particularly important for skill-based sports, which incorporate multi-articular and coordinated movement patterns to intercept a ball or shuttle. Apart from requiring optimal physiological fitness, interceptive sports, such as baseball, cricket, hockey and tennis, require a significant amount of hand–eye coordination to perform successfully.[2] The complexity of interceptive sports is governed by the temporal and spatial constraints defined by each sport. Therefore, traditional coaching places great importance on the training of these technical and cognitive skills for the enhancement of athletic performance.

Traditional coaching techniques are heavily dependent on the expertise of past generations, often presented in coaching manuals of previously successful sports men and women.[3] The focus is often manifested in teaching the 'perfect' technique required to master a movement pattern, despite the knowledge of 'degrees of freedom,[4,5] and individual variability. Formal practices are quick to adopt these principles, with coaches often lacking support to experiment with more

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evidence-based training methods that are becoming more common in sports research.

There has recently been an increase in research investigating the usefulness of alternative methods of technical and cognitive training.[6–8] Constraints-led training is a variation from traditional training regimes which provides athletes with a greater representation of the sporting environment in order to train specific match skills.[9] This has been introduced to assist with the development of various skills, techniques and decision-making abilities to further improve the performance, as well as improve the quality and quantity of training.

The constraints-led approach was introduced in motor learning to assist with the development of skills and techniques through the manipulation of specific task, individual or environmental constraints.[6,7] The approach is based on the theory of ecological dynamics, whereby performance is understood to result from the interaction of the individual and the environment.[6] The ecological dynamics approach perceives humans to be complex, nonlinear, neurobiological systems that act in accordance with unstable, evolving environments to produce movement actions necessary to perform a given task.[7,10] The unstable environments provide individuals with specific 'affordances' (*def*. opportunities for action) that influence the outcome of the action required (Fajen et al.,[11] p.79).

The approach argues that the training of individuals in isolation of their 'real performance settings' should be viewed with scepticism, as it does not provide the representative affordances that could be expected in 'real performance settings'. Traditional training regimes are prone to focus on the breakdown of movement patterns required for a particular sport. For example, cricket batsmen hone their techniques by means of formal net practices. This breakdown provides 'bite-size' movement sequences to allow for easier training toward a 'correct' or 'perfect' technique. However, the focus on this form of training often neglects the importance of the affordances provided by training in a representative environment. Maintaining the cricket example, batsmen should be afforded the opportunity to train in a 'real performance setting' in order to coordinate the technique with the requirements of the batting task as well as the constraints supplied from the sport's rules and regulations.[12–15] Incorporating all these aspects might produce a movement action that may differ to the one being trained in the traditional net setting.

Theoretically, the ecological dynamics approach to training design and environmental evaluation should afford athletes opportunities that would be associated with real performance environments.[10] These environments should allow individuals greater quality (and possibly quantity) of training, thereby providing improved transfer of learning to real world environments. Using a tennis example, manipulating the court size by decreasing the surface area may provide a greater opportunity to prolong rallies for low-skilled participants, thereby increasing the quantity of hitting during training sessions.[16]

The key principles behind this approach are that of functionality and action fidelity.[17] Functionality refers to the degree to which the task maintains the perception–action coupling present in real performance environments; whereas action fidelity refers to the degree to which the training environment reflects that of the real performance environment.[17] The constraints-led approach encourages the design of a training environment that affords individuals a high level of functionality as well as a high degree of action fidelity.

Most studies on constraints-led training within interceptive sport focus on the manipulation of a single facet within the task in an attempt to provide individuals with alternative means of learning task-relevant skills. For example, Stretch et al.[18] attempted to train cricket batsmen to improve their accuracy of hitting the ball in the middle of the bat; this was done through the use of a modified bat, one-third the width of regulation size.[18] However, constraints-led training may make use of multiple constraint manipulations in order provide individuals with improved methods of training while maintaining the principles of the ecological dynamics approach.

Currently, there is a lack of sufficient evidence to advocate whether the manipulation of specific task constraints benefit individuals more so than traditional training regimes. A recent review by Buszard et al.[19] discussed how scaling equipment and playing field in children improve motor skill acquisition. However, to the authors' knowledge, there are no review papers which summarize the evidence for or against constraints-led training intervention studies which specifically relate to skill acquisition in interceptive sports across all age groups. As such, the purpose of this review is to systematically examine the current status of the literature specifically relating to the effects of constraints-led training interventions on skill development within interceptive sports for children and adult athletes. The review will also critically compare and discuss the strengths and weaknesses of the various methodologies used to investigate the effects of these interventions.

Methods

A systematic review was chosen to summarize evidence which support or reject the use of a constraints-led approach in training interventions.

The inclusion/exclusion criteria were constructed keeping in mind that only studies which investigated interceptive sports, played by both children and adults, were to be assessed.

Search strategy and study selection

The search strategy made use of four online databases to locate and retrieve journal articles that were sourced using keywords related to 'skill development', 'intervention training', 'constraint manipulation' and 'interceptive sport'. The following array of keywords and phrases were used: (technical skill OR motor skill OR co-ordination) AND (development OR acquisition) AND (interceptive action OR cricket OR baseball OR tennis OR hockey) AND (manipulation OR constraints-led OR task requirements OR ecological dynamics) AND (practice OR training OR learning). The multidisciplinary databases of Google Scholar, JURN, Mendeley and Science Direct were used with no publication date restrictions. By not restricting dates, all past studies related to constrain-led training approach could be available for screening. Only academic journal articles, predominantly favoured from the Journal of Sport Science, were included in the search. The 'advanced search' option was selected within the Mendeley and Science Direct databases. The disciplines of 'Education', 'Psychology' and 'Sports and Recreation' were selected within the Mendeley database in an attempt to reduce the number of irrelevant journal articles. The remaining databases were searched in their entirety for relevant open-access journal articles, with the 'advanced search' option proving ineffective.

Potential articles underwent a three-phase screening process. The initial phase of screening was performed on the title, this was followed by the screening of the abstract, and finally the full text was read and screened for selection. Figure 1 provides the detail of the PRISMA flowchart representing each stage of the screening process as well as explanation for articles excluded during each screening phase (adapted from Moher et al.[20]).

The selection of studies to be included for review followed a specific inclusion/exclusion guideline (Table 1).

Data extraction

The extracted data included the population characteristics, type of interceptive sport, constraint manipulated, intervention design, number of training sessions afforded to the participants and the overall outcome effect of the intervention that was implemented.

Table 1. The inclusion and exclusion criteria used during the screening process.

Inclusion criteria	Exclusion criteria
Intervention training	Dissertations not peer-reviewed
Interceptive sport	Physiological/biomechanical effects
Constraint manipulation	
Skill-based assessments	
Peer-reviewed publications	

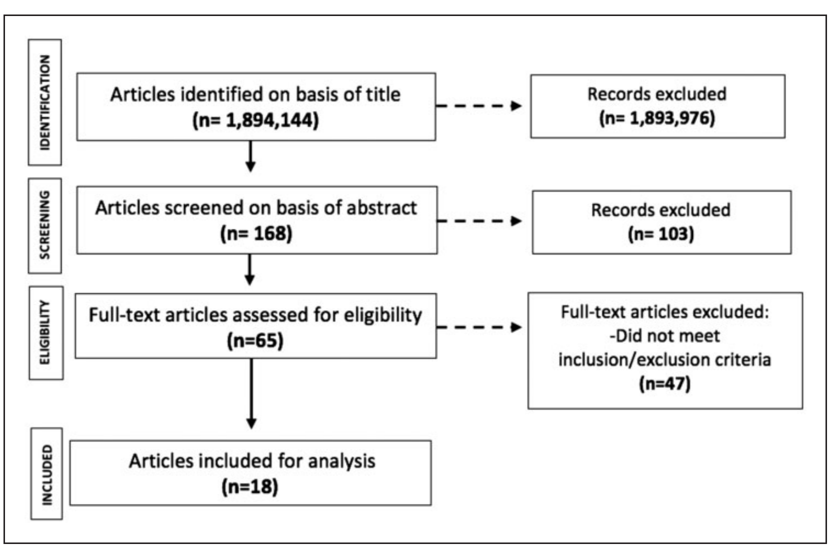

Figure 1. The screening process of journal articles for study selection.

Quality assessment and reporting guidelines

Quality assessment checklists from the Cochrane Collaboration Handbook 5.1.0 (http://handbook.cochrane.org/) were consulted and a reporting guideline was obtained from the EQUATOR Network (www.equator-network.org/) in order to assess the quality of the methodology and reporting within each study. It is important to note that 'methodological quality' and 'reporting quality' are not interchangeable terms, as is commonly implemented in practice.[21] Methodological quality refers to 'the appropriateness of the methods employed in the design and conduct of epidemiological research, which determines the reliability of findings (i.e. internal validity)' (Da Costa et al.,[21] p.4). Reporting quality refers to 'the completeness with which a study is presented and whether major items for the proper appraisal of internal and external validity of findings are clearly reported' (Da Costa et al.,[21] p. 4).

The quality assessment tool used to appraise the methodological quality of studies was the domain-based evaluation tool recommended by the Cochrane Collaboration.[22] This tool is used to evaluate the design of the research methodology, providing a risk of bias score for each study.[22] The tool considers the randomisation of participants; blinding of participants, researchers, and outcome assessments; as well as incomplete data and selective reporting. This assessment was performed to appraise the risk of bias within each study.

As the studies included in the review were of a case–control nature, a specific reporting guideline was required to assess reporting quality. The STROBE checklist for case–control studies was extracted from EQUATOR Network and used to assess the reporting quality of the studies included for review. The STROBE checklist was designed to assess whether key aspects of the study are reported throughout the article.[21] The STROBE reporting guidelines relating to important aspects of the study design were: title and abstract, background, objectives, study design, setting, participants, variables, data sources, bias, study size, quantitative variables, statistical methods, descriptive data, main results, other analyses, key results, limitations, interpretation, generalisability and funding. Each study was scored out of a total of 22 points.

Results

Screening process

The keyword search for the online databases resulted in a match of 1,894,144 journal articles (duplicates not accounted for), of which 168 were retrieved based on the relevance of the title to the topic of discussion. Not all 1,894,144 titles were read, the search engines categorize articles according to relevance of the keyword search; therefore, after five pages of irrelevant article titles (i.e. 50 articles), the search was stopped and a new combination of keywords was searched. The 168 articles that were retrieved were then screened according to abstract; again, this was to assess the relevance of the article to the topic of discussion. Only 65 article abstracts satisfied the relevance to the topic. These 65 articles were then reviewed in their entirety and judged according to the inclusion/exclusion criteria stipulated for this review. These articles were read in full text, with 18 articles satisfying the inclusion criteria and which were included for review.

Study characteristics

In total, 804 participants across 18 studies were included in the analyses along with three types of constraint manipulations (Table 2). Six studies were on adult participants, nine studies on minors and three studies included both adults and minors.

The breakdown of constraints implemented within each study is shown in Table 3.

Methodological quality scores

From the domain-based quality assessment guideline obtained from the Cochrane Collaboration Handbook (v5.1.0), the following results for methodological quality were found for the risk of bias within each study.

The result of the methodological quality assessment is summarized in Table 4. The total quality assessment ranged from five to ten out of a maximum 12 points. The greater the score the greater, the risk of bias is within the study. Eight of the studies scored greater than six indicating a high risk of bias within those studies. These assessment scores need to be interpreted along with the reporting quality assessment scores in order to discuss possible reasoning behind different levels of success among the studies included.

Reporting quality scores

From the reporting guideline checklist, the following scores successfully satisfied the specific items ($n = 22$) of the checklist:

The result of the reporting quality assessment is summarized in Table 5. The greater the percentage score, the better the reporting quality of the study. The average number of items reported in the studies was more than half of the 22 items ($n = 13.3$; 60.3%). Oppici et al.[23] reported the greatest number of items within their study ($n = 19$; 86.4%), with Moradi et al.[24] reporting the least ($n = 9$; 40.1%).

Table 2. Study characteristics summary.

#	Study	Sport	Intervention	Population	Participation	Training sessions	Outcome effect
1	Stretch et al.[18]	Cricket	Spatial	16–24 Years, male	Intervention ($n=9$), control ($n=9$)	15	Both[a]
2	Turner and Martinek[25]	Field hockey	Informational	11–14 Years	Intervention[1] ($n=30$), intervention[2] ($n=30$), control ($n=11$)	15	[b,c]
3	Vickers et al.[26]	Baseball	Informational	18–38 Years	Intervention ($n=134$), control ($n=115$)	5	Both[a]
4	Williams et al.[27]	Tennis	Informational	18–25 Years, male	Intervention[1] ($n=8$), intervention[2] ($n=8$), intervention[3] ($n=8$)	3	[b]
5	Raab et al.[37]	Table tennis	Informational	8–15 Years	Intervention ($n=10$), control ($n=10$)	45	N/A
6	Williams et al.[27]	Soccer	Perceptual	12 Years, male	Intervention[1] ($n=6$), intervention[2] ($n=6$), control ($n=6$)	1	[d]
7	Hagemann et al.[28]	Badminton	Informational	18–35 Years	Intervention[1] ($n=23$), intervention[2] ($n=20$), control ($n=20$)	1	[b]
8	Caserta et al.[29]	Tennis	Informational	>50 Years	Intervention[1] ($n=8$), intervention[2] ($n=9$), control ($n=10$)	5	[b]
9	Mazyn et al.[30]	Catching	Perceptual	16–30 Years, female	Intervention ($n=8$), control ($n=9$)	8	[b]
10	Masters et al.[36]	Table tennis	Informational	18–25 Years	Intervention[1] ($n=17$), intervention[2] ($n=18$)	1	[d]
11	Farrow and Reid[16]	Tennis	Spatial	7–9 Years	Intervention[1] ($n=6$), intervention[2] ($n=5$), intervention[3] ($n=6$), control ($n=6$)	5	[b]
12	Moradi et al.[24]	Basketball	Perceptual	16–19 Years, male	Intervention ($n=14$), control ($n=14$)	15	[d]
13	Ryu et al.[31]	Soccer	Perceptual	19–26 Years, male	Intervention[1] ($n=9$), intervention[2] ($n=10$), control ($n=9$)	7	[b,c]
14	Buszard et al.[19]	Tennis	Spatial	6–8 Years, male and female	Intervention ($n=40$), control ($n=40$)	1	[b]
15	Hernandez-Davo et al.[33]	Tennis	Informational	10–15 Years	Intervention ($n=15$), control ($n=15$)	12	[b]
16	Kachel et al.[34]	Tennis	Spatial	9–11 Years, male and female	Intervention ($n=26$), control ($n=20$)	1	[b]
17	Oppici et al.[23]	Futsal and Soccer	Spatial	13–15 Years, male	Intervention[1] ($n=17$), intervention[2] ($n=20$)	3	[b]
18	Timmerman et al.[35]	Tennis	Spatial	9–11 Years, male	Intervention ($n=16$), control ($n=16$)	1	[b]

[a]The effectiveness of the intervention was dependent on the level of skill of the participants.
[b]Positive outcome effect in intervention group.
[c]Control groups were either trained in a different sport code or were afforded no training sessions.
[d]No outcome effect in intervention group.

Table 3. The constraints implemented within each study.

#	Author	Sport	Intervention	Constraint A	Constraint B
1	Stretch et al.[18]	Cricket	Spatial	Equipment scaling	
2	Turner and Martinek[25]	Field hockey	Informational	Tactical awareness and decision-making	Technical skill instruction
3	Vickers et al.[26]	Baseball	Informational	Behaviour training	Decision training
4	Williams et al.	Tennis	Informational	Perception-action training	Perception-only training
5	Raab et al.[37]	Table tennis	Informational	Behavioural training	Decision training
6	Williams et al	Soccer	Perceptual	Visual occlusion	
7	Hagemann et al.[28]	Badminton	Informational	Attentional cues	Video training (no cues)
8	Caserta et al.[29]	Tennis	Informational	Situational awareness training	Technical-footwork training
9	Mazyn et al.[30]	Catching	Perceptual	Task difficulty variation	
10	Masters et al.[36]	Table tennis	Informational	Explicit instruction	Analogical instruction
11	Farrow and Reid[16]	Tennis	Spatial	Equipment scaling	
12	Moradi et al.[24]	Basketball	Perceptual	Visual information (full vision)	Visual information (target only)
13	Ryu et al.[31]	Soccer	Perceptual	Guided perceptual training	Unguided perceptual training
14	Buszard et al.	Tennis	Spatial		
15	Hernandez-Davo et al.[33]	Tennis	Informational	Equipment scaling	Consistent conditions
16	Kachel et al.[34]	Tennis	Spatial	External condition variation	
17	Oppici et al.[23]	Futsal and Soccer	Spatial	Equipment scaling	
18	Timmerman et al.[35]	Tennis	Spatial	Playing area and equipment scaling	

Table 4. Total quality assessment scores (0–12 scale) which were obtained by assigning studies 1 point for 'unclear' and 2 points for 'high' bias ('low' risk resulted in zero points).

#	Authors	Sequence generation	Allocation concealment	Participant blinding	Outcome blinding	Incomplete outcome data	Selective Reporting	Total quality assessment
1	Stretch et al.[18]	Low	High	High	High	Low	Low	**6**
2	Turner and Martinek[25]	High	High	High	High	Low	High	**10**
3	Vickers et al.[26]	Low	High	High	High	Low	Low	**6**
4	Williams et al.	High	High	Low	High	Low	Low	**6**
5	Raab et al.[37]	Unclear	Low	High	High	Low	High	**7**
6	Williams et al.	High	High	High	High	Low	Low	**8**
7	Hagemann et al.[28]	High	High	High	High	Low	Low	**8**
8	Caserta et al.[29]	Low	Unclear	High	High	Low	Low	**5**
9	Mazyn et al.[30]	High	High	High	High	Low	Low	**8**
10	Masters et al.[36]	Low	High	High	High	Low	Low	**6**
11	Farrow and Reid[16]	Unclear	High	High	High	Low	Low	**7**
12	Moradi et al.[24]	High	High	High	High	Low	Low	**8**
13	Ryu et al.[31]	Low	High	High	High	Low	Low	**6**
14	Buszard et al.	Low	High	Low	High	Low	Low	**4**
15	Hernandez-Davo et al.[33]	High	High	High	High	Low	Low	**8**
16	Kachel et al.[34]	Low	High	High	High	Low	Low	**6**
17	Oppici et al.[23]	Low	High	Low	High	Low	Low	**4**
18	Timmerman et al.[35]	Low	High	High	High	Low	Low	**6**

Table 5. Results from the reporting guideline of the STROBE checklist.

	Study number																		
Checklist	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	*Mean*
Title and abstract	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Introduction																			
Background	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Objectives	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Methods																			
Study design	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	
Setting							✓	✓			✓			✓		✓	✓	✓	
Participants			✓		✓					✓							✓	✓	
Variables	✓		✓		✓		✓		✓	✓	✓			✓		✓	✓	✓	
Data sources	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	
Bias					✓					✓	✓			✓			✓		
Study size																			
Quantitative variables					✓														
Statistical methods	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Results																			
Participants			✓							✓							✓	✓	
Descriptive data					✓														
Outcome data					✓												✓	✓	
Main results	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Other analyses	✓			✓	✓		✓			✓	✓			✓		✓	✓	✓	
Discussion																			
Key results	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Limitations	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	
Interpretation	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Generalisability	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Other information																			
Funding																	✓		
Overall score	13	11	13	12	18	11	13	11	12	16	15	9	11	14	11	13	19	17	**13.3**
Percentage (%)	59.1	50	59.1	54.5	81.8	50	59.1	50	54.5	72.7	68.2	40.1	50	63.6	50	59.1	86.4	77.3	**60.3**

Discussion

The main discovery from this systematic review was that 77.7% (14 out of the 18 studies) of the studies favoured the constraints-led approach, which is sufficient evidence to adjudicate that constraints-led training has a greater benefit for technical skill development compared to normal training regimes.

Analysis and outcomes of constraints-led research

The training interventions had mixed outcomes (refer to Table 2), with 14 studies finding significant performance improvements for constraints-led training,[16,18,23,25–35] of which three found an effect for a particular skill level.[18,26,28] Further, three studies found no significant performance improvements during constraints-led training[1,24,36] and one study failed to complete analysis due to a questionable study design.[37] Raab et al.[37] failed to measure objective performances for the control group, and therefore the eventual outcome of the constraints-led intervention could not be compared to the experimental group. To accept this result as valid and reliable would be incorrect and as such, the outcome effect of this study has been excluded from discussion. The study has not been completely removed from the review, as it is still valid for discussion on strengths and weaknesses of constraints-led training methodology.

Of the three studies that found a significant effect for a particular skill level, Stretch et al.[18] and Hagemann et al.[28] found results that benefited only unskilled cricket and badminton players respectively, with no benefit shown for the skilled participant group in either study. In contrast, Vickers et al.[26] found that a constraints-led approach benefited intermediate to advanced baseball hitters rather than novices. While both these findings are important for constraints-led training literature, the results cannot be categorized into the significant effect grouping as only a certain demographic benefited from this particular training. What it may suggest is that this type of training may be more beneficial for less skilled individuals.

Two studies[25,31] compared the effects of different training interventions across two experimental groups and one control group (Table 2). However, the control groups within each of these studies were either trained in a different sport[25] or were not afforded the opportunity to train.[31] As such, the authors excluded the comparison with these control groups from their analysis of the studies. The comparison between the two intervention groups within each study were used for the analysis of the effectiveness of these constraints-led training interventions.

A majority of the studies investigated the use of a constraints-led approach in the skill development of tennis players by specifically, modifying task constraints such as variable serving techniques,[33] and the scaling of equipment[16,32,34] court size[16] and net height.[35] Variation in motor patterns and downscaling was shown to improve serving accuracy and accelerate skill acquisition, respectively; thus, the majority of these studies supported the modification of task constraints in the coaching of specifically junior tennis players.[16,32–35,38] By downscaling racquets and court-sizes, the number of hitting opportunities was increased which led to greater stroke development and a greater enjoyment of the game in young players.[16–32] Further, a lower compression ball (75%) was found to permit an increase in rally speeds and lower striking height for ground-strokes when compared to a regular tennis ball.[34] It has been suggested that lowering the net height for younger players could lead to an increased participation in the sport, as Timmerman et al.'s[35] study showed that participants were able to play more aggressively and were seen to enjoy playing under the scaled conditions. Conversely, Williams et al.[27] found no significant difference between perception–action and perception-only training styles on anticipatory performance in an adult population. This contradictive result found between participant age may suggest that a constraints-led approach is more successful in skill acquisition of younger tennis players compared to an older population.

Oppici et al.[23] manipulated the ball, playing surface and individual playing area as constraints during futsal and soccer practices. The results showed that despite each group performing a passing action, futsal and soccer task constraints shaped athletes' perceptual skills. Higher game intensity, opponent pressure and a reduced number of players in futsal led players to acquire information on other players' behaviour prior to and during ball control. Conversely, more players, lower game intensity and unpredictable ball behaviour in soccer led players to scan the playing environment when they did not have ball possession.[23]

Strengths and limitations: Methodology

One of the objectives of this review was to discuss the strengths and weaknesses of the methodology of the included studies to assist with the future development of methodology within this field of research.

The result of the methodological and reporting quality assessments found that both measures averaged more than half of the items for the included studies (see Tables 4 and 5). However, neither the reporting quality nor the methodological quality was able to predict a reason for positive or no effect, as important aspects of the studies were not assessed. These important aspects include the sample size, length of intervention, study design and level of participants' skill. Therefore, these areas would need to be assessed more carefully to gain an understanding of the quality of the results of each study.

Sample size

More than half of the studies ($n = 8$) had relatively small sample sizes, between 6 and 10 participants per group, which may have had an impact on the reliability of the results. Consequently, the outcome effect of these studies may have been distorted. Of the studies with small sample sizes, only one study had no effect for constraints-led training (Williams et al.[39]: *soccer*), one study had questionable methodology and was therefore removed from discussion (Raab et al.[37]: *table tennis*), and the remaining six all showed some signs of benefit for the experimental group (Stretch et al.[18]: *cricket*; Caserta et al.[29]: *tennis*; Williams et al.[27]: *tennis*; Mazyn et al.[30]: *catching*; Farrow and Reid[16]: *tennis*; Ryu et al.[31]: *soccer*).

Intervention period

Eleven studies made use of a very short intervention training period, ranging between one and five sessions overall, which may have influenced the reliability of the results. Six studies made use of only one session for the intervention (Williams et al.[39]: *soccer*; Hagemann et al.[28]: *badminton*; Masters et al.[36]: *table tennis;* Buszard et al.[32]: *tennis*; Kachel et al.[34]: *tennis*; Timmerman et al.[35]: *tennis*), two studies consisted of three intervention sessions (Williams et al.[27]: *tennis;* Oppici et al.[23]: *futsal and soccer*) and the remaining three studies had five intervention sessions each (Vickers et al.[26]: *baseball*; Caserta et al.[29]: *tennis*; Farrow and Reid[16]: *tennis*). It is important to note that the two studies, which found no effect for the training-led approach only used one intervention (Williams et al.[39]: *soccer*; Masters et al.[36]: *table tennis*).

The length of the training intervention should be scrutinized as the period should afford participants with an adequate opportunity to learn and develop. The reason is that longer duration studies have a higher degree of external validity and mimic real-life scenarios to a greater extent than shorter ones.[40] Therefore, there is reason to suggest that intervention periods of between one and five sessions do not allow sufficient time to train under the comparative training regimes (constraints-led vs. traditional training). Further, the length of intervention should reflect the complexity of the skill required for each specific sport.

Study design

Experimental vs. control. When investigating the possible effects of a training intervention, making use of a case–control study design allows for the best comparison. Some of the studies included in this review made use of experimental and control groups for comparison, whereas other studies made use of two or more experimental groups to compare the effects of the training intervention.

One study showed bias towards the experimental groups, with 85% of the participants assigned to one of two experimental groups.[25] The remainder of the participants was assigned to the control. This setup engenders unreliable results, due to a greater amount of data for the experimental group/s.

Cross-over design. A good measure to counteract a small sample size is a cross-over trial design. This allows both groups to experience the effects of the training intervention, thereby providing strong evidence for its success or failure. Four studies made use of a cross-over design (Williams et al.[39]: *soccer;* Buszard et al.[32]: *tennis*; Kachel et al.[34]: *tennis*; Timmerman et al.[35]: *tennis*). Three of the studies found a constraints-led training effect (Buszard et al.[32]: *tennis;* Kachel et al.[34]: *tennis*; Timmerman et al.[35]: *tennis*); however, only one did not (Williams et al.[39]: *soccer*).

Retention tests. Retention or follow-up tests are used with some success in intervention studies to determine the type of learning effects that are found following the intervention period.[29] Retention tests allow researchers to determine whether participants experience transient performance, or functionally significant learning effects.[29]

Four studies made use of retention tests to identify the type of learning effect that was found (Vickers et al.[26]: *baseball*; Hagemann et al.[28]: *badminton*; Ryu et al.[31]: *soccer*; Moradi et al.[24]: *basketball*). Vickers et al.,[26] Hagemann et al.[28] and Ryu et al.[31] found that there was greater benefit following the intervention period, indicating functionally significant learning effects. Moradi et al.[24] found no effect following the retention test.

Controlled training. Only two studies controlled the amount of additional practice that participants could perform outside of the allocated intervention training period (Farrow and Reid[16]: *tennis;* Oppici et al.[23]: *futsal* and *soccer*). This ensured that all participants were exposed to the same amount of training throughout the intervention phase, negating any performance effects due to the volume of training hours.

The remaining studies neglected this aspect, with the possibility that participants may train over and above the intervention requirements. Consequently, findings from such studies may be misinterpreted.

Participant skill level (experience)

Two studies accounted for both skill levels within the methodological design. While one study found that unskilled individuals experienced greater benefit than skilled individuals in a constraints-led training drill (Stretch et al.[18]: *cricket*), the other study found that intermediate to advanced participants experienced greater benefit compared to novice individuals (Vickers et al.[26]: *baseball*). Incorporating skill level within the study design has its own strengths and weaknesses. On the one hand, making use of different skill levels allows researchers to identify specific methods for different skill levels. On the other hand, this design complicates the overall effectiveness of the training intervention, as it might only be successful to a specific group. As such, the results of these two studies made it difficult to categorize the effectiveness of constraints-led training, as it found the training technique to be beneficial to some and not to others.

Three studies only used skilled athletes[23,34,35] and one study only used unskilled athletes.[32]

Strengths and limitations: Quality assessments

The results from the methodological and reporting quality assessments should be investigated further to gain a true understanding of their meaning. Firstly, the reporting guideline is just that, a guideline for epidemiological studies to ensure that a quality assessment can be performed on the internal and external validity of the study design.[21] Some items are essential for a scientific paper and these have, for the most part, been correctly documented within the included studies. However, other items within the guideline are not necessary for the production and publication of a scientific research paper and are understandably overlooked when writing up the final product.

In terms of the quality assessment scores, the methodological quality of the study is determined according to the risk of bias, with three of the six items concerned with participant or researcher blinding. Therefore, if studies fail to incorporate blinding in the study design, they are predisposed to a high risk of bias due to the number of the items relating to that specific area. Most of the studies included in this review did not perform blinding procedures and therefore scored 'high' for risk of bias (Table 4). It is important to note, however, that blinding for the studies analysed within this review and those similar is not possible due to the experimental nature of these studies and access to participants. However, other important methodological designs such as sample size, intervention period and the control of additional training sessions were not accounted for in any assessments and these should be considered important aspects that may have an influence over the outcome of the training interventions, and therefore the quality of the study design.

The reporting guideline takes into consideration a whole range of items without weighting each item according to greater importance. As a result, some studies may have reported a number of minor aspects of the research study but failed to include some essential information resulting in a higher reporting quality than other studies. As such, the guideline may result in a relatively low reporting quality of the studies included for review (Table 5).

Bias analyses

The main features highlighted for risk of bias analysis have been discussed below:

Sequence generation: There were seven studies that failed to report the generation of comparison groups (Turner and Martinek[25]: *field hockey*; Williams et al.[39]: *soccer*; Williams et al.[27]: *tennis*; Hagemann et al.[28]: *badminton*; Mazyn et al.[30]: *catching*; Hernandez-Davo et al.[33]: *tennis*; Moradi et al.[24]: *basketball*), whereas two studies had an 'unclear' rating for bias (Farrow and Reid[16]: *tennis*; Raab et al.[37]: *table tennis*), and the remaining five studies indicated that sample groups were randomly generated. The two studies that were rated as an 'unclear' risk of bias was due to 'quasi-random selection'.

Allocation concealment: Sixteen of the studies did not identify whether researchers were blinded to the allocation of participants. The only two studies that controlled for the blinding of researchers were that of Caserta et al.[29] (*tennis*) and Raab et al.[37] (*table tennis*).

Participant blinding: Only three studies controlled for the blinding of participants to the knowledge of which intervention group they were a part of (Williams et al.[27]: *tennis;* Buszard et al.[32]: *tennis;* Oppici et al.[23]: *futsal and soccer*). The remaining studies did not report whether they controlled for this in their study designs and were rated with a 'high' degree of bias.

Outcome blinding: All studies failed to report the control for outcome blinding, resulting in a 'high' bias rating.

Incomplete outcome data: No studies reported a lack of outcome data or missing data. All studies were rated with a 'low' risk of bias.

Selective reporting: Two studies were rated with a 'high' risk of bias for 'selective reporting'. One study made conclusions on the basis of objective performance data collected from one intervention group (Raab et al.[37]: *table tennis*). The other study made comparisons between groups with the control group receiving non-specific training to the task (Turner and Martinek[25]: *field hockey*).

Limitations to intervention studies

Depending on the target population and the type of intervention put in place, intervention studies may come with limitations of their own. Firstly, implementing an intervention within a controlled sports environment requires the cooperation from a number of parties, including prospective coaches, players and possibly parents (for minors).

A further limitation relates to the type of sport receiving the intervention, including the length of season (if it is a seasonal sport), the influence of weather on practice/ participation (if sport is played outdoors), or any other factors that may influence the controlled flow of the intervention period.

Sport coaches may find it difficult to understand the need for stringent control across all variables during the study protocol, as they are not accustomed to the required standards of scientific research. Therefore, it is important for researchers to educate sport coaches about the necessity to control all aspects of the training procedure in order to be able to identify where differences may occur, which may in turn detract from cooperation with the research study altogether.

Conclusion

As the majority of the studies found a positive effect in skill acquisition following manipulation in training protocol, the implementation of the constraints-led approach within interceptive sport can be advocated. However, the studies had sub-standard quality levels in terms of whole-study reporting as well as methodological risk of bias. There were certain characteristics across each study which either benefited or hindered the quality of the results. These include aspects such as the sample size, the length of the intervention period, the type of study design and the skill level of participants.

This provides the opportunity for researchers to collect more compelling evidence to answer the question: '*Does constraints-led training assist with the development of technical skills within interceptive sport*'?

Future research should consider implementing better quality control in the methodological design. For small sample sizes, consideration should be given to the use of cross-over trial designs in order to strengthen the reliability of the results. Retention tests could be used to determine the type of learning (if any) that occurred as a result of the intervention. Depending on the type of intervention, participant skill and/or experience level are important factors to consider.

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