RUNNING HEAD: PRINCIPLES FOR LEARNING DESIGN IN SPORT

# Principles for use of ball projection machines in elite and developmental sport programmes.

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## Contents

**Figure Caption**

Figure 1. A principled theoretical framework for the future design of experimental and practice tasks involving ball projection machines.

**Abstract**

Use of ball projection machines in the acquisition of interceptive skill has recently been questioned. The use of projection machines in developmental and elite fast ball sports programmes is not a trivial issue, since they play a crucial role in reducing injury incidence in players and coaches. A compelling challenge for sports science is to provide theoretical principles to guide *how* and *when* projection machines might be used for acquisition of ball skills and preparation for competition in developmental and elite sport performance programmes. Here, we propose how principles from an ecological dynamics theoretical framework could be adopted by sports scientists, pedagogues and coaches to underpin the design of interventions, practice and training tasks, including the use of hybrid video-projection technologies. The assessment of representative learning design during practice may provide ways to optimize developmental programmes in fast ball sports and inform the principled use of ball projection machines.

Ball projection machines typically play an integral role in practice and training environments in many sports from cricket and baseball to volleyball and tennis. Recently, it has emerged that not all skilled performers agree that the use of projection machines in practice provides a functional task to practice interceptive actions, leading to some contention among expert coaches. For example, some high performance and developmental programmes have taken steps to extensively reduce the use of these machines in the sport of cricket.[1] Greg Chappell, a former prominent Australian cricket batsman and head coach of the National Centre of Excellence, now national team selector and talent development manager describes his stance:

*"...what my intuition told me for years was that the bowling machine was a totally different exercise from batting against the bowler. From my own personal experience of batting against the bowling machine, it wasn't a great experience because once I've done it a few times I decided that it wasn't going to help me with batting. I was better off not to bat at all than to go and bat on a bowling machine because the activity is so different. [In an actual cricket match] you know the bowler's preparation to bowl; you know everything—all of the cues and clues that you're getting from the bowler is really important to get into the rhythm of the bowler and to get the timing of your movements. You take the bowler out of the equation, you stick a machine there that spits balls out at you and you've lost all those cues and clues. What I've subsequently found is that research is telling us what my intuition and my experience was telling me. The other thing is that the research into expertise tells you that experts are better at picking up the cues and clues than the average player. So why take it away from everyone and stop them from developing the things that will help them get better?"*[1]

Conversely, the late Bob Woolmer, an equally respected and renowned former international batsman and national coach of South Africa and Pakistan, considered the ball machine one of the *'most essential tools in modern cricket.'* [2] One of the primary uses of projection machines in practice seems predicated on movement repetition,[2] considered traditionally as an essential feature of 'perfecting' a putative 'ideal' technique in the process of skill acquisition.[3,4] This idea is exemplified in the most up-to-date coaching literature on cricket batting which discusses the use of ball machines to help 'groove the skill.'[2] Additionally, projection machines allow individuals to achieve a high volume of practice by facing more balls in a short period of time in order to practise specific actions hundreds of times. This is not only a critical issue for sports coaches, but a very important theoretical and methodological one for sport science researchers.

## 1. The problem of practice volume

Projection machines provide relatively consistent and accurate practice conditions, which developing athletes (e.g., pitchers, bowlers) may not be capable of producing for their peers. This is important since skill acquisition in interceptive actions has been associated with large volumes of task-specific practice.[5] However, an over-reliance on projection machines may have been inadvertently induced by some perspectives of expertise which have over-emphasised practice volume (e.g., quantity of balls hit) over the quality of practice task design. Practice volume is central to many prevalent perspectives on expertise, such as the 10,000 hour rule,[6] the power-law of practice,[7] and deliberate practice.[8] To exemplify, the most comprehensive and relevant coaching literature in cricket batting proposes that batsmen require *'10,000 repetitions of an action or skill to penetrate the subconscious'* and that this conditioning *'enables the batsmen to react instinctively in match conditions'*.[2] In complex skilled actions, it is important to consistently achieve a particular performance outcome; however it has been demonstrated that skilled movement patterns are rarely repeated in an identical way on two or more occasions as performance outcomes are achieved.[9] The need for 'repetition without repetition' in practice is a critical feature of successful motor-learning,[10,11] with performers using movement variability and stability paradoxically to achieve performance outcome consistency and movement pattern adaptability.[11] This is important to note since the ways in which projection machines are currently used appears to be focused on stability and blocked practice of isolated movement aspects (e.g., blocked practice of a single type of shot).

But how does one practice multi-articular actions for an extended number of trials and for prolonged periods of time, without placing too much stress on the bodies of coaches, pitchers or bowlers? The practical benefits of projection machines have been highlighted by research into overuse injuries in sports relying heavily on multi-articular projecting actions (e.g., baseball pitching, cricket bowling). A clear advantage gained from using ball projection machines is that they alleviate the workload required from bowlers or pitchers during batting practice. This is most important since, in cricket, bowling injuries are heavily attributed to overuse through high bowling workloads, particularly at developmental stages.[12,13] Critically, once a player sustains an injury, the likelihood of re-occurrence is increased.[13,14] Similar findings exist in baseball with overuse injuries of the shoulder being a primary concern for developing performers.[15,16] A recent prospective study demonstrated that youth athletes pitching more than 100 innings per calendar year were significantly more likely to sustain injury. To counter the problem of injuries, many coaches in cricket rely heavily on providing simulated actions such as 'throw downs' (overarm throws from a reduced distance) to replicate ball flight information and maintain the temporal demand reminiscent of bowling. However, there is some anecdotal evidence from the coaching literature of similar levels of overuse injuries in coaches using 'throw downs' to simulate bowling deliveries in cricket.[2] In light of these data it is apparent that use of projection machines in practice programmes remains important in reducing the risks of injury incidence.

## 2. Implications for skill acquisition

As well as being perceived as a benefit in reducing injury incidence, ball projection machines are also primarily considered as useful tools for the acquisition of skilled hitting actions; allowing a performer to focus on one isolated movement aspect (e.g., a specific shot or stroke), practice individually, and complete large volumes of practice in a short period of time. Despite these reasons, some studies assessing the use of projection machines in sports performance have questioned their role in athlete preparation, skill acquisition and assessment. There is clear evidence that use of projection machines in tennis and cricket creates significant differences in timing and control of performers' actions, as well as a reduction in the quality of interception when compared to facing a 'live' opponent delivering a ball with the same characteristics.[17-20] Especially in developing junior performers, these differences are manifested in significant delays in movement initiation times which increase the temporal demand on the unfolding action. For example, it has been reported that developing junior cricket batters initiated the backswing of the bat and front foot movement significantly later when performing front foot shots (e.g., moving the front foot towards ball bounce) against a projection machine set to the same speed ($\approx 28\ m\cdot s^{-1}$) and with similar trajectory characteristics as a 'live' performer.[17] Critically, these delays in movement initiation resulted in a reduction in quality of contact of the interceptive action, a reduction in bat swing speeds, and significantly shorter step lengths;[19] the need to place the foot as close to the pitch of the ball in these type of shots (e.g., minimising the impact of late ball-flight deviation) is a well established cricket coaching principle. Changing the practice task constraints and using projection machines in junior cricket batting leads performers to re-organise their actions in attempts to achieve the required spatial-temporal orientation.[19,21] Here we argue that differences exist between performance contexts and training task constraints because the latter are used to simulate the former. Differences may exist between specific training tasks and competitive match contexts. This is a rich area for future research to address using the principles we outline below (see section 3).

As noted earlier, critically relevant information sources from the competitive performance environment are not available under practice task constraints involving projection machines. Research suggests that in their current mode of use, prolonged exposure to projection machine practice tasks may lead athletes to attune to information sources which are not present during competitive performance, leading to a predictive rather than prospective control strategy emerging in learners.[18,22] Renshaw and colleagues[18] demonstrated that, contrary to data reported for junior performers, experienced cricket batters initiated the backswing of the bat earlier against a projection machine than when batting against an experienced medium-paced bowler at the same bowling speed ($\approx$27 m $s^{-1}$) (also see[23]). It has also been recently demonstrated that highly distinctive visual search patterns are used by experienced cricket batters when practising with projections machines since they 'park' their gaze at a point on the anticipated trajectory of the ball before release.[22] Although it is intuitive to predict differences between batting performance contexts, no research has yet compared visual strategies of batters under ball projection machine *and* 'live' bowler task constraints. The use of a principled framework for these comparisons would support analyses to observe whether differences between the two tasks might emerge. However, a key point to note is that the use of projection machines reduces the opportunities for developing batters to attune to subtle and relevant sources of pre-ball release information from a bowler/ pitcher's movements for differentiating ball trajectory, speed or ball type variations (e.g., different spin rotations), a critical feature of expertise in interceptive skill.[24-26] This criticism can also be directed at the use of 'throw downs' to simulate bowling deliveries in cricket. For these reasons, Pinder et al.[17] have cautioned against an 'over-reliance of ball projection machines in developmental programmes'. But it is important to note that this message should not be interpreted as: ‘ball machines should not be used at all during practice’. Rather, practitioners and sport scientists need to develop a principled theoretical rationale for their use as a skill enhancement tool in sport, which we elucidate next.

## 3. Principles for Future Work

A compelling challenge for sports science is to understand *how* and *when* projection machines might be used for acquisition of ball skills and preparation for competition. Ecological dynamics is a theoretical framework which could underpin a reasoned analysis for use of ball machines in developmental and elite sport programmes. Ecological dynamics is predicated on ideas of ecological psychology and dynamical systems theory, with a level of analysis embedded in the performer-environment relationship.[27,28] This theoretical framework proposes that movement behaviours emerge from dynamic interactions between neurobiological movement systems and their performance environments.[9,29] The interaction between performer, environmental and task constraints results in the emergence of patterns of movement behaviour that become stabilised through learning and practice.

A model based on the tenets of ecological dynamics has already been outlined for sport scientists, coaches, experimental psychologists, and pedagogues, to underpin the design of training interventions practice tasks in sport.[30] The model was predicated on concepts from ecological dynamics and a nonlinear pedagogy (see[11] for recent reviews of skill acquisition in sport). Assessment of ‘representative learning design’ in specific practice tasks allows sport scientists to understand the functionality and limitations of particular training environments. Understanding representative learning design may provide opportunities to optimize learning programmes in sport and inform use of performance enhancement tools, such as projection technology, during practice. To assess representative learning design of specific tasks, practitioners should consider the functionality of the practice task constraints in allowing performers to pick up and use information sources representative of the performance context (e.g., by comparing visual search strategies between projection and ‘live’ bowler/ pitcher situations). Since information regulates actions, an important principle is that the key perception and action processes which are coupled in a competitive performance environment should be maintained in the design of practice task constraints. In simulations, the degree of association between practice and performance contexts should be analysed by considering the fidelity of the performer’s actions (for a detailed overview see Pinder et al.,[30]), such as by measuring and comparing movement organisation between the different contexts (see Figure 1).

**Insert Figure 1 about here**

Principles of representative learning design are summarised in Figure 1. The use of projection machines should be considered to understand how they might alter learners’ emergent spatio-temporal responses, movement coordination and visual search behaviours, when compared to facing a real bowler during competitive performance. Future research is needed to explore ways to increase the functionality of current practice tasks involving ball projection machines. For example, it was recently reported that a specific ‘near life-size’ video simulation task which maintained a coupling between perception and action processes, allowed the action fidelity of cricket batters’ preparatory and initial movement responses to be maintained when compared to facing a ‘live’ bowler.[19] Recent technological advances, which combine both video and ball projection machines (e.g. ‘ProBatter’ – ProBatter Sports, LLC), may have a significant future in elite sport and development programmes.

However, caution is needed with these new technologies, and the assessment of their representative learning design may help identify the benefits and limitations of these hybrid training tasks. As discussed, Croft et al. [22] found that against projection machines experienced batters fixated their gaze at a point on the anticipated trajectory of the ball from the machine. As 'ProBatter' systems release the ball from a specific position (a screen with one hole), it needs to be verified whether the pickup and use of information in that simulation task actually replicates the competitive performance context. Due to the high current cost of high fidelity ball projection systems, the standard projection machine is likely to remain prominent in development programmes for some time. For this reason, researchers should focus on carefully assessing and designing the informational properties of a competitive performance environment that might be replicated at different development and skill levels. This level of analysis is needed to provide insights into the nature of the transfer of interceptive actions performed against projection machines and real bowlers, for instance when comparing visual search strategies under both task constraints.

## 4. A future role for ball projection machines?

The relevance of projection machines to be part of training programmes for team game performance is not under question. The key issue is how best to use them during practice. Current research does not advocate removal of ball projection machines from cricket training programmes, since investigation of their use is still in its infancy. Research has not yet examined their role in high and low ball delivery speeds or looked at their effect on timing and co-ordination in back foot shots (where a cricket batter moves backwards from their initial position to intercept a ball which bounces closer to the bowler and reaches the batter around or above waist height).

An important challenge is to examine their role in developing interceptive actions in early and more advanced learners in ball sports. In the very early stages of learning when the focus should be on the construction of a basic coordination pattern from all the possible degrees of freedom, it is expected that the stable and consistent practice conditions would greatly benefit the rate of learning[31] (also see Davids, Button & Bennett[9] for a review). To exemplify in cricket batting, ball projection machines could be used to deliver the ball to a restricted spatial location so that learners stabilise a functional stroke, such as a forward defensive or straight drive. Developing athletes, in particular, need to be provided with opportunities to establish functional and stable relationships between perception of information from the performance environment and their movements.[9,32] However, later in learning it is clear that stability *and* variability of practice task constraints may allow for the development of more adaptable performers.[33] At later stages of learning, ball projection machines could be used to locate the learner in a *meta-stable* region of a perceptual-motor workspace. In this region learners remain in a state of relative coordination with the practice environment, being unable to function completely independently, nor dependently, on environmental information to regulate their actions. In the meta-stable region, functional movement solutions can emerge during task performance, for instance when learners need to decide whether to move forwards or backwards in playing cricket batting strokes). By accurately projecting the ball onto specific locations of the cricket pitch, more advanced learners can be forced to enter a meta-stable region of batting performance to enrich performance during practice (see[34] for an example in boxing). These theoretical ideas imply that traditional blocked practice methods utilising ball projection technology may prevent more advanced learners from harnessing motor system degeneracy to functionally adapt stable patterns of movement organization, and may actually be dysfunctional when transferring to more dynamic performance contexts.[35]

As a principle, therefore, it seems that, at all stages of learning, the role of projection machines may be to *supplement* rather than *replace* the role of the 'live' bowler in the acquisition of batting actions. Ensuring a balance between the use of projection machines and bowlers may also ensure that batters are able to constantly attune and recalibrate (recognise and adjust) to differences in ball flight characteristics under the distinct practice contexts and establish important information-movement couplings. However, further research is needed to assess the effects on skill acquisition of different volumes (amount of time) of supplementary practice in fast ball sports (e.g., visual training through video simulation designs or ball projection machines) on the acquisition of skilled performance in fast ball sports.

Additionally, variations in ball speed and trajectories (e.g., constant changes in bounce location) may allow increased opportunities for batters to exploit and master the perceptual degrees of freedom which support adaptive movement behaviours needed during performance (see Savelsbergh et al.,[36]). Intuitively, it would be predicted that when there is a reduced temporal constraint on batters' actions, such as when playing against slow bowling, ball-flight information might become more salient (i.e., less reliance on pre-release information) and could provide opportunities for increased action fidelity when using projection machines. Ball projection machines, as outlined previously, are able to replicate the same ball speeds and angle of release as a 'live' performer, providing some level of 'representativeness' of practice task information. Therefore, the consideration and assessment of the representative design of ball projection machines nested within particular performance contexts (e.g., middle wicket practice with typical game demands) may increase action fidelity at more elite levels. With respect to this idea, it is important to note that most projection systems available to practice batting in cricket do not currently support the use of balls with the same properties as those typically used during competitive performance. This is a major issue since expert performers have been shown to use seam characteristics of balls to support perceptual decision making in fast ball sports.[37] The use of tasks which more closely replicate the flight and bounce characteristics of a ball used in competitive performance should become a focus for future work.

## 5. Conclusion

Using projection machines in sport should not be considered dysfunctional. Importantly they help alleviate workload stresses on bowlers or pitchers during ball delivery which can lead to overuse injuries in developing and elite performers. Nevertheless, it is disingenuous to call ball projection machines ‘bowling machines’ because they can only generally simulate post-ball release information sources during batting practice. They do not allow learners to pick up specific sources of pre-ball release information from bowlers’ actions, a vital part of the information-movement coupling link in batting performance. Current practices of using such projection technology in athlete development programmes can be enhanced by using theoretically guided principles to underpin their implementation as a skill acquisition and performance preparation tool in ball sports. Principles of ecological dynamics suggest that: (i) their use is likely to differ according to the needs of different skill groups; (ii) they are most functional when used in high fidelity simulations of performance environments (e.g., nested in performance settings such as in middle wicket practice in cricket, or in combination with video simulations); and (iii) they should supplement practice with ball projection by real individuals so that all learners can attune to the affordances provided by movements of opponents during ball delivery.

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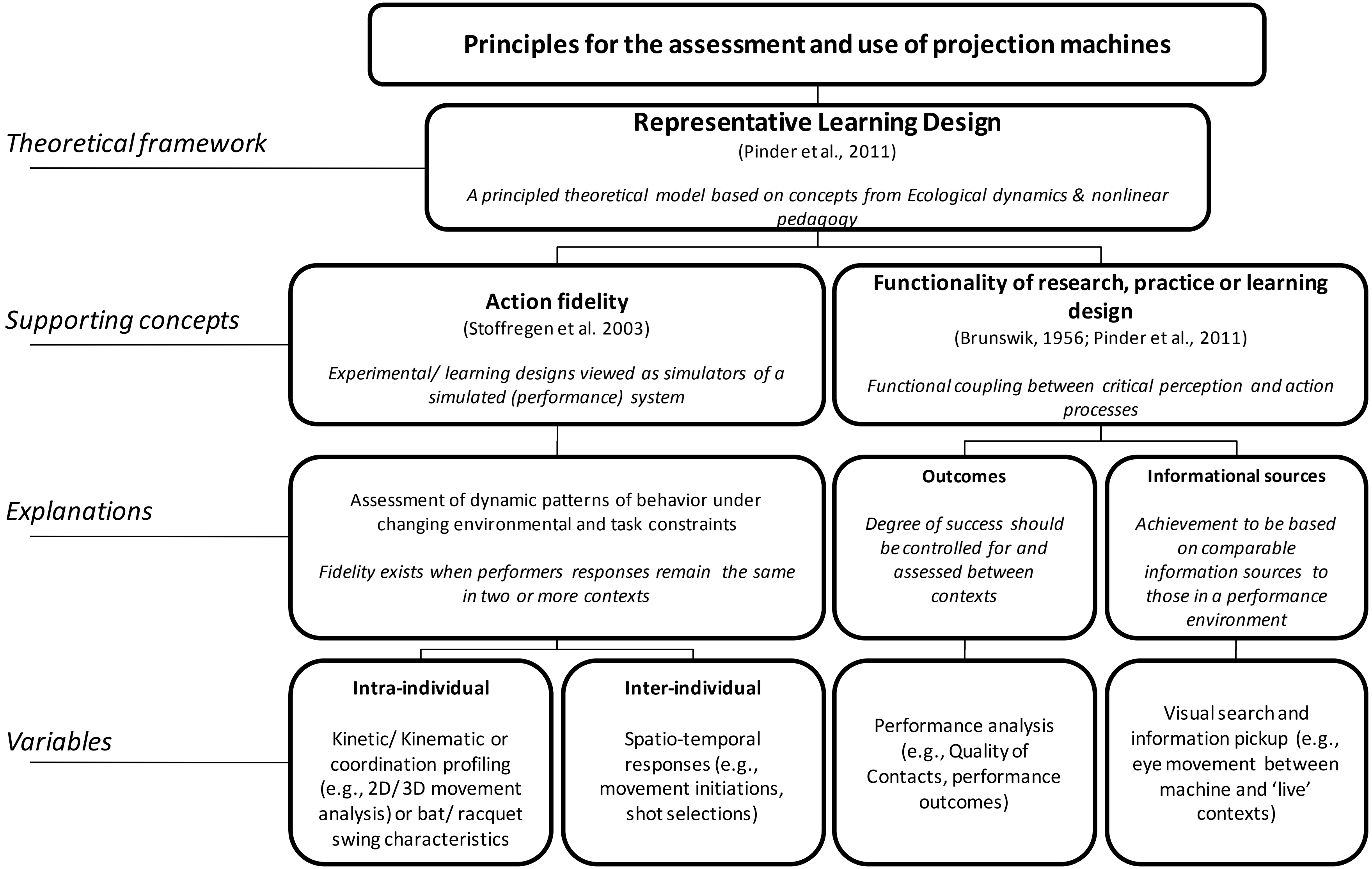
Principles for the assessment and use of projection machines
Theoretical framework
Representative Learning Design
(Pinder et al., 2011)
A principled theoretical model based on concepts from Ecological dynamics & nonlinear pedagogy
Supporting concepts
Action fidelity
(Stoffregen et al. 2003)
Experimental/ learning designs viewed as simulators of a simulated (performance) system
Functionality of research, practice or learning design
(Brunswik, 1956; Pinder et al., 2011)
Functional coupling between critical perception and action processes
Explanations
Assessment of dynamic patterns of behavior under changing environmental and task constraints
Fidelity exists when performers responses remain the same in two or more contexts
Outcomes
Degree of success should be controlled for and assessed between contexts
Informational sources
Achievement to be based on comparable information sources to those in a performance environment
Variables
Intra-individual
Kinetic/ Kinematic or coordination profiling (e.g., 2D/3D movement analysis) or bat/ racquet swing characteristics
Inter-individual
Spatio-temporal responses (e.g., movement initiations, shot selections)
Performance analysis (e.g., Quality of Contacts, performance outcomes)
Visual search and information pickup (e.g., eye movement between machine and 'live' contexts)