

QUT Digital Repository:
<http://eprints.qut.edu.au/>



This is the post-print, accepted version of this paper. Published as:

Pinder, Ross A. and Renshaw, Ian and Davids, Keith (2009) *Information–movement coupling in developing cricketers under changing ecological practice constraints*. *Human Movement Science*, 28(4). pp. 468-479.

© Copyright © 2009 Elsevier B.V. All rights reserved.

Information-movement coupling in developing cricketers under changing ecological practice constraints

Ross A. Pinder ^{a,b,*}, Ian Renshaw ^b, Keith Davids ^b

^a School of Human Movement Studies, Queensland University of Technology, Victoria Park Road, Kelvin Grove, QLD 4059, Australia

^b Sheffield Hallam University, Collegiate Crescent, Sheffield, S10 2BP, United Kingdom

* Corresponding author.

Tel.: +61 7 313 85750

Email: ross.pinder@qut.edu.au

Abstract

Changing informational constraints of practice, such as when using ball projection machines, has been shown to significantly affect movement coordination of skilled cricketers. To date, there has been no similar research on movement responses of developing batters, an important issue since ball projection machines are used heavily in cricket development programmes. Timing and coordination of young cricketers ($n=12$, age = 15.6 ± 0.7 years) were analysed during the forward defensive and forward drive strokes when facing a bowling machine and bowler (both with a delivery velocity of $28.14 \pm 0.56\text{m}\cdot\text{s}^{-1}$). Significant group performance differences were observed between the practice task constraints, with earlier initiation of the backswing, front foot movement, downswing and front foot placement when facing the bowler compared to the bowling machine. Peak height of the backswing was higher when facing the bowler, along with a significantly larger step length. Altering the informational constraints of practice caused major changes to the information-movement couplings of developing cricketers. Data from this study were interpreted to emanate from differences in available specifying variables under the distinct practice task constraints. Considered with previous findings, results confirmed the need to ensure representative batting task constraints in practice, cautioning against an over-reliance on ball projection machines in cricket development programmes.

PsychINFO classification: 2330

Keywords: Dynamic interceptive actions; ecological constraints; information-movement coupling; movement coordination; skill development

1. Introduction

Batting in cricket is a quintessential example of a dynamic interceptive action in sport, and an ideal vehicle for studying interactions between perception and action (Stretch, Bartlett & Davids, 2000). Ecological psychologists have attempted to describe the control mechanisms involved in regulating movement to satisfy specific task constraints in interceptive actions (e.g. Davids, Renshaw, & Glazier, 2005; Montagne, Cornus, Glize, Quaine, & Laurent, 2000; Montagne, 2005). James Gibson's theory of Direct Perception proposes how movement is shaped using information constantly available in the surrounding environment (e.g., Gibson, 1979). It has become clear how performers can exploit information to regulate action from movements of other players (see Renshaw & Fairweather, 2000; Renshaw, Oldham, Davids, & Golds, 2007) or moving objects (see Regan, 1997; Williams, Davids, & Williams, 1999).

From this viewpoint the process of practice involves becoming better attuned to specifying variables available in different performance contexts (Davids, Button, & Bennett, 2008), and calibrating movement responses to those variables. Since the perception of environmental information is specific and constrained by each individual performance setting, it is important that learners improve their capacity to detect specifying from non-specifying variables (see Jacobs & Michaels, 2002; see also, Dicks, Davids, & Araújo, 2008). In particular performance contexts, specifying variables provide more functional information to constrain performers' actions than non-specifying variables (Araújo, Davids, & Passos, 2007).

Learners pick up specifying variables to support action in specific performance environments through the education of attention, or perceptual attunement (Jacobs & Michaels, 2002; Fajen, Riley, & Turvey, in press). Jacobs and Michaels (2002) suggested that

the two stages of constructing information-movement couplings are: a) the education of attention to key informational sources, and b) the fine tuning of movements to a 'critical information source' (Davids et al., 2005). Clearly, the removal of critical information sources at specific developmental stages could impede learning, resulting in unintended changes to coordination of actions. Therefore, while practice task constraints might contain some specifying variables which are available to support learners' actions during *practice* tasks (i.e. batting against a bowling machine), learners should also be provided with opportunities to pick up specifying variables available to support performance in competitive contexts. It is important that practice task constraints should not lead learners to pick up non-specifying variables for competitive performance environments.

Batting against a bowling machine affords learners to become perceptually attuned to ball flight information during practice. Clearly, while specifying variables may be available from ball flight characteristics when batting against bowling machines, these variables may be non-specifying in competitive performance environments due to the time constraints on action. In cricket batting the time constraints are often severe with ball velocities typically ranging from 19-40m·s⁻¹ (Bartlett, 2003). Thus, when facing medium to fast deliveries from a bowler, batters have to decide on an appropriate shot and initiate it within about 0.7 s (McLeod & Jenkins, 1991). These findings highlight that, due to ball velocities generated by bowlers, batters need to attune to specifying variables that exist in bowlers' actions prior to ball release which are available in competitive performance environments (Abernethy & Russell, 1984; Weissensteiner, Abernethy, Farrow, & Müller, in press).

Specifying variables for action need to be constantly available for perception in the practice and performance environment (Dicks et al., 2008). Practice task constraints that provide specifying variables for pick up by learners during competitive performance can be considered to be high in *representative task design* (see Araújo et al., 2007). Changing the

informational constraints in practice environments might lead to the design of less representative practice tasks by altering availability of specifying variables, resulting in changes to a learner's acquisition of functional movement patterns (Beek, Jacobs, Daffertshoffer, & Huys, 2003). The pick-up of non-specifying variables might result in performance success under specific task constraints, but perceivers may become too dependent on these variables even when performance task constraints change (Beek et al., 2003). Dependent on the specific performance context, this unintended reliance may not be a problem. As Withagen (2004, p242) highlighted 'a human being who intercepts 70% of the balls thrown at him or her because she exploits a non-specifying, moderately informative variable will not die because of it'. However, Withagen (2004) noted the significance of becoming better attuned to specifying variables by arguing that 'the animals that do survive are the ones that do better than their competitors'. In sports performance, as levels of competition increase, those athletes that continue to rely on non-specifying variables will eventually become less competitive than their counterparts who have learned to pick up specifying variables to regulate actions.

1.1. The use of ball projection machines

Based on these ideas, an important question is: How does altering the informational constraints in specific practice environments affect the coordination of dynamic interceptive actions, such as cricket batting? Some previous work has demonstrated how ball projection machines (e.g., cricket bowling machines) influence the movement patterns of skilled cricketers (Renshaw et al., 2007). Bowling machines in cricket are considered to be useful equipment to allow performers to practice batting movements away from the performance environment. They are considered to provide consistent, accurate and specific conditions for practice (e.g. bowling pace or length) to enable batters to acquire individual shot types. One

clear advantage of bowling machines is that they alleviate the workload required of developing bowlers, with overuse injuries being a major concern (Dennis, Finch, & Farhart, 2005). Nevertheless, a key issue is whether practising with a bowling machine may actually impede the pick-up of specifying information variables from the performance environment for batting (Renshaw et al., 2007).

The role of anticipation is firmly established as a key component of expert performance in dynamic fast ball sports, with the use of pre-ball flight information viewed as essential to skilled cricket batting (Müller & Abernethy, 2006). Research in cricket batting has demonstrated a relationship between skill level and anticipation, consistent with those seen in other sports (Müller, Abernethy, & Farrow, 2006). Current evidence from expertise research suggests that only skilled batters have an ability to utilise information from the pre-release actions of a bowler (Weissensteiner et al., in press). They can gain an advantage, under severe time constraints, by picking up information from limb and body orientations of the bowler during the run-up, bound and moment of release (Davids et al., 2005). Skilled performers use this information to predict 'line and length' of deliveries from both fast (e.g., Abernethy & Russell, 1984; Penrose & Roach, 1995; McRobert & Taylor, 2005) and slow bowlers (e.g., Renshaw & Fairweather, 2000), in addition to specifying the point of ball release (Gibson & Adams, 1989). In contrast, less-skilled players appear to gain little information from pre-release sources, relying primarily on ball flight characteristics (Renshaw & Fairweather, 2000). A number of reasons have been proposed to explain why developmental level performers may not be able to pick up information from a bowler's actions. First, it is felt that the lower bowling speeds faced by batsmen in junior competition may not necessarily require them to anticipate for success. This is because the time from ball release to bat contact is long enough to make the need to attune to pre-flight information redundant. A second related suggestion is that anticipation makes a less significant

contribution to successful performance in developing athletes, compared to factors such as relative age, strength and maturity in determining success in junior cricket batting (Weissensteiner et al., in press).

However, recently van der Kamp, Rivas, van Doorn & Savelsbergh (2008) have criticised the occlusion paradigm on which these assumptions are based. Typically, occlusion studies have tended to examine perception in isolation from action, suggesting that the actual performance of experts in these tests may not be truly 'expert'. For example, these authors collated results from a number of key occlusion studies noting significant spatial errors in predicting landing location of an object even under full vision conditions for both novices and experts (e.g. in badminton 1.4-1.8m, Abernethy & Russell, 1987; in cricket wicket-keeping 45-55 inches, Houlston & Lowes, 1993; in soccer, 3.3m, McMorris & Colenso, 1996; in squash, 0.6-1.8m, Abernethy, Gill, Parks, & Packer, 2001) (van der Kamp et al., 2008). Re-evaluation of these data suggested that the occlusion paradigm has significant limitations and highlights the need to analyse anticipation in tasks such as cricket batting by examining perception and action in unison.

1.2. Adaptations to practice constraints in cricket batting

The most common stroke in cricket is the forward defensive which also forms the basis of the drive (Stretch, Buys, Dutoit, & Viljeon, 1998), and consequently, it is often the starting point for many coaches when teaching novices. A previous two-dimensional analysis of the forward defensive stroke in cricket batting (Renshaw et al., 2007) examined the movement coordination and timing of four 'high intermediate' standard batsmen during the forward defensive stroke, against a medium pace bowler and bowling machine ($26.76 \text{ m}\cdot\text{s}^{-1}$). Significant adaptations were observed under the two different informational constraints and central to these changes was the organisation of the two phases of bat swing. The backswing

in the bowling machine condition varied greatly, but was coupled to ball release (0.02 ± 0.10 s after ball release), whereas against the bowler, initiation of the backswing occurred later (0.12 ± 0.04 s). Similarly, initiation and speed of the downswing occurred earlier and more quickly when facing the bowling machine (0.32 ± 0.04 s; bowler: 0.41 ± 0.03 s), resulting in different ratios of backswing-downswing between conditions.

The findings of Renshaw et al., (2007) are somewhat different to other data on cricket batting by Gibson and Adams (1989). Utilising a case study approach, Gibson and Adams (1989) observed how one international cricketer initiated the backswing before ball release, with front foot movement occurring much earlier when facing the bowling machine compared with the bowler. This observation was rather surprising, and could be attributed to the experimental task constraints (i.e., the batsman knew in advance the landing position of the ball) or the previous experience of the participant facing the bowling machine. Renshaw et al. (2007) observed no differences in front foot initiation time under both practice task constraints, noting that it was more closely coupled with the backswing when facing the bowler ($r = 0.88$; bowling machine, $r = 0.65$), and occurred after ball release in both conditions. Additionally, it was observed that a higher peak bat height was reached against the bowler (1.56 ± 0.20 m vs. 1.72 ± 0.10 m), as well as a longer front foot stride (0.55 ± 0.07 m vs. 0.59 ± 0.06).

Differences in co-ordination patterns observed in these two studies when facing both the ball machine and bowlers highlighted the importance of ecological task constraints. Practice under the two distinctive ecological task constraints led to variations in functional movement solutions which might be attributed to differences in the practice task constraints (i.e., not knowing in advance versus knowing in advance where the ball would land) as well as to the absence of advanced information from the bowler. To explain their findings, Renshaw et al. (2007) proposed that the previous experiences of these relatively skilled

batsman against a bowling machine might have led participants to rely on non-specifying variables provided by the machine (Renshaw et al., 2007). This strategy may have been employed by the skilled participants because of the removal of important information sources from the bowler. These explanations signalled the need for further empirical research to examine the movement responses of developing players under similar practice task constraints. This is a significant practical issue because bowling machines are used extensively in the development of young cricketers. In this regard, an important point to note is that ball projection machines prevent the use of advanced information sources available prior to ball release (e.g. the run-up, bound and delivery stride of a bowlers approach). Currently it is not clear whether the pick up of kinematic and early ball flight information can be utilised by children.

Therefore, the aim of this study was to extend understanding of information-movement coupling in cricket batting by assessing the timing and kinematic responses of developing batters under two practice task constraints, when performing an attacking (forward drive) and defensive (forward defence) stroke. It was anticipated that less-skilled individuals would demonstrate differences in the temporal and spatial movement responses, leading to shorter strides and lower peak bat heights when facing the bowling machine. It was also predicted that observation of a bowlers' movements might afford advanced information sources that allowed developing players to initiate movements earlier than against a bowling machine, providing them with more time to organise their responses.

2. Method

2.1. Participants

Eight right-handed and four left-handed junior batsmen (n=12, age = 15.6 ± 0.7 years), with 6.6 ± 0.6 years playing experience, provided informed consent and took part in

the study. Ethical clearance was completed through a local university ethics committee. The batters were adjudged by skill acquisition specialists (who were also qualified Level II ECB cricket coaches) to be representative of individuals at the control stage in Newell's (1985) model of skill acquisition, and were considered to have received similar amounts of task-specific practice. Using this assessment, participants were classified as "less-skilled" than those studied in previous work (see Renshaw et al., 2007). Four left-arm bowlers (age = 15.0 \pm 0.8 years) with similar, representative actions for medium-fast bowlers of the same developmental status were asked to participate in the study.

2.2. Apparatus and experimental set-up

The study took place at an indoor cricket school which was the regular practice facility of the participants. Mean bowling speed ($28.14 \pm 0.56\text{m}\cdot\text{s}^{-1}$) was assessed for the four bowlers using a sports radar gun (Stalker Radar, Texas), and mean height of release ($2.06 \pm 0.07\text{m}$) was calculated. This information was next used to set up a bowling machine (Jugs Inc., Tualatin, Oregon) to mirror the release height and bowling speeds of the bowlers. All batters had some limited experience of practising with the bowling machine as part of their training programme. The machine was operated by an experienced Australian level 3 coach. The same balls ("Oz" bowling machine balls) were used to maintain consistency of bounce across conditions. A video camera (Sony HVR-V1P) was positioned 10m from the plane of action perpendicular to the batting crease following standard set-up procedure (see Bartlett, 2007). A second synchronised camera was used to simultaneously capture the point of release from the bowler or the emergence of the ball from the bowling machine. Both cameras were set to a frame rate of 100 Hz, and a shutter speed of 1/300s. The image of the batters was maximised in the field of view in front of a plain uncluttered background, and calibration was attained using horizontal and vertical references (metre rules). Participants wore full

protective equipment, including batting helmets. Markers were placed on specific body locations before filming as in previous research (Renshaw et al., 2007), allowing for comparisons. Contrasting markers were placed on the foot (proximal phalanx of the big toe), ankle (malleolus), knee (estimated axis of rotation), hip (greater trochanter), shoulder (greater tubercle of the humerus), elbow (lateral epicondyle of the humerus), and wrist (head of the ulna). For the knee and ankle, markers were placed on the pads covering the joint/location, and remained in the same places between trials. Additionally, one marker was placed on the helmet and two on the edge of the bat facing the camera. This marker set was chosen to replicate previous research and enable recording of segment angles of the knee and elbows, in addition to initiation timings at key phases, bat heights, and step lengths (Renshaw et al., 2007).

2.3. Data collection procedure

Participants faced the bowlers and bowling machine in a counterbalanced design to control for order effects, and none had previously faced any of the four bowlers but had faced bowlers of similar speed and ability in practice. Bowlers were asked to bowl as they would in a game, ensuring that the batters were unsure of the upcoming delivery due to variations in length. The length was equally varied in the bowling machine condition without the batters being aware of subtle changes to the angle of the machine, ensuring similarity between both conditions. This was important, as previous research has described how bowling machines may allow for more certainty, therefore enabling a batter to initiate front foot movement earlier than against bowlers (Gibson & Adams, 1989). Batters, therefore, were required to play both forward and back with little certainty over upcoming deliveries. A series of lines on the floor in front of the batters enabled consistency of shots chosen for analysis. Due to individual constraints (e.g. height and segment lengths), coaches' assessments were used to

determine the correct lengths (bounce point) for the defence and drive of individual batsmen. These areas in line with the stumps, measured 0.23m in width and 1m in length, and were used to determine which shots constituted a forward defence and a forward drive in both the bowler and bowling machine conditions. Bowlers ensured that the batters were ready before beginning their approach, and a standard 'feeding' routine (see Renshaw et al., 2007) was used in the bowling machine to enable consistency and safety.

2.4. Data analysis

A total of 288 shots were used for temporal analysis, 72 forward defensive strokes and 72 forward drives in both the bowler and machine conditions (six for each batsman in each condition), based on the explained criteria. The forward defensive shots were used for kinematic analysis, to provide comparisons with previous research. Data were analysed using SIMI motion software, with key phases selected for analysis. Means and standard deviations of the relative timing between phases were calculated. These data included the point of release, backswing initiation, initiation of front foot movement, initiation of downswing, front foot placement, and at the ball's impact with the bat. As in previous research (Renshaw et al., 2007), the protocol employed was to consider the first video frame of a specific event, for example, the initiation of the front foot movement to show when the foot was first lifted off the ground. Parametric assumptions were met, and each dependent variable (event initiation, bat height, step length or angle) was compared between the bowler and machine condition using paired-samples t-tests, for both defence and drive shots. Additionally, effect size (r) was calculated to observe if significant effects were substantive, and to judge the relative magnitude and importance of each dependent variable (Mullineaux, Bartlett, & Bennett, 2001). Finally, Pearson's correlation coefficient was used to assess the relationship between backswing initiation and front foot movement.

3. Results

Insert Fig. 1 about here

3.1. Temporal and spatial differences

Significant differences were observed in the timing and initiation of key phases of the forward defence and forward drive strokes (see Fig. 1) Results are represented in seconds before the impact of bat and ball, with ball release in both conditions occurring 0.64s before impact. Initiation of the backswing occurred earlier against the bowler than against the bowling machine for the defence (B: 0.58 ± 0.07 s; BM: 0.49 ± 0.08 s, $t(65) = 8.27$, $p < .001$, $r = 0.72$) and the drive (B: 0.58 ± 0.07 s vs. BM: 0.50 ± 0.07 s, $t(65) = 8.82$, $p < .001$, $r = 0.74$). Similarly, the developing batters initiated the downswing of the bat earlier when facing bowlers compared with the bowling machine, for both defence (B: 0.22 ± 0.06 s; BM: 0.20 ± 0.05 s, $t(71) = 2.59$, $p < .05$, $r = 0.29$) and drive strokes (B: 0.19 ± 0.05 s; BM: 0.17 ± 0.04 s, $t(71) = 3.38$, $p < .005$, $r = 0.37$), $t(71) = 3.38$, $p < .005$, $r = 0.37$). Peak height of the backswing was measured (see Fig. 2), with batters swinging higher against the bowler during the defence (B: 1.34 ± 0.29 m; BM: 1.27 ± 0.31 m, $t(65) = 2.48$, $p < .05$, $r = 0.29$) and drive (B: 1.52 ± 0.25 m; BM: 1.41 ± 0.26 m, $t(65) = -4.71$, $p < .001$, $r = 0.50$). These differences amounted to slightly longer backswings when facing the bowler (defence: 0.36s; drive: 0.39s) compared with the bowling machine (defence: 0.29s; drive: 0.33s). Initiation of the downswing occurred earlier and lasted longer against the bowler compared to the bowling machine. This combination of reduced bat height and shorter backswing and downswing periods when facing the bowling machine resulted in very little difference in the ratio of backswing-downswing timings (B – defence: 63-37%, drive: 69-31%; BM – defence: 61-39%, drive: 67-33%).

Front foot movement initiation occurred earlier against the bowler compared with the bowling machine for the forward defence (B: 0.47 ± 0.11 s; BM: 0.39 ± 0.09 s, $t(71) = 7.35$, $p < 0.001$, $r = 0.66$) and the forward drive (B: 0.48 ± 0.08 s; BM: 0.41 ± 0.08 s, $t(71) = 10.22$, $p < 0.001$, $r = 0.77$). Correspondingly, front foot placement occurred significantly earlier in the bowler condition, for both defence (B: 0.10 ± 0.05 s; BM: 0.06 ± 0.04 s, $t(71) = 4.58$, $p < 0.001$, $r = 0.48$) and drive strokes (B: 0.09 ± 0.03 s; BM: 0.05 ± 0.03 s, $t(71) = 8.00$, $p < 0.001$, $r = 0.69$). These timings resulted in a shorter total time to complete the front foot stride when facing the bowling machine (defence: 0.33s; drive: 0.36s) compared to a bowler (defence: 0.37s; drive: 0.39). Additionally, we measured the length of the stride at front foot placement (see Fig. 3). Significant differences were found between the bowler and bowling machine conditions, with larger strides when facing a bowler for the forward defence (B: 0.76 ± 0.17 m; BM: 0.71 ± 0.16 m, $t(65) = 2.14$, $p < 0.05$, $r = 0.25$) and forward drive (B: 0.89 ± 0.13 m; BM: 0.84 ± 0.15 , $t(65) = 3.80$, $p < 0.001$, $r = 0.41$).

****Insert Fig. 2 and Fig. 3 about here****

3.2. Backswing and front foot movement coupling

The relationships between the initiation of the backswing and the front foot movement were marginally stronger in the bowling machine condition for both the defence (B: $r = 0.38$, $p < .01$; BM: $r = 0.47$, $p < 0.01$) and the drive (B: $r = 0.42$, $p < 0.01$; BM: $r = 0.48$, $p < 0.01$). It is clear that despite the changing ecological constraints and delayed initiations, developing players were able to coordinate the initial movements of the upper and lower extremities to a similar degree.

****Insert Table 1 about here****

3.3. Kinematic differences

Knee and elbow angles were recorded throughout the key phases of the forward defensive stroke (see Table 1), with significant changes observed corresponding to the temporal findings previously described. Changes in knee and elbow joint segment angles demonstrated differences in backswing-downswing coordination and movement on the front foot. Smaller angles of the front ($r = 0.40$) and back elbows ($r = 0.37$) at the point of front foot initiation when facing the bowlers corresponded to the earlier initiation of the backswing. Similarly, at the initiation of the downswing, smaller elbow angles (front: $r = 0.48$; back: $r = 0.42$) were observed due to higher bat swings in the bowler condition. At front foot placement, front and back elbow angles were significantly larger in the bowling machine condition (with moderate effects), demonstrating that the arms were more extended and further forward. Additionally, a key difference at impact was the larger knee angle during the bowling machine condition, suggesting players stood in a more upright position (possibly as a result of the shorter stride), as observed in Fig. 4.

****Insert Fig. 4 about here****

3.4. Individual analysis

To support the group analysis, we checked the performance trends in individual batsmen to ascertain whether group results were consistent across all participants. Bat heights and step lengths were highly consistent throughout the group, with 90% of individual findings matching those observed in the group analysis. The few instances where they did not follow the trend were characterised by only small differences (0.03-0.09m) and larger variances in the bowling machine condition. Further analysis of the temporal responses

demonstrated almost complete consistency across all 12 participants; with only one batter showing a tendency to initiate later movement (i.e. downswing and front foot placement) against the bowling machine when playing a forward defence.

4. Discussion

This study sought to manipulate practice task constraints to evaluate effects on movement control and coordination of developing cricket batters. The aim was to investigate whether the information-movement couplings used during batting by developing players changed when facing a bowler and bowling machine. Based on previous work, if the developing players were not attuned to advanced information sources from bowlers, then relatively smaller changes in movement responses between the conditions would be expected, compared with data from more skilled batters (Renshaw et al., 2007).

Data showed that batting against a medium-fast bowler and a bowling machine produced significant adaptations to movement timing and coordination of both a defensive and an attacking stroke. The major differences observed appear to have been a result of the delayed initiation of the backswing and front foot movements during the bowling machine condition. Under bowling machine and bowler conditions developing players demonstrated a similar level of coupling between these two components of batting actions. However, when batting against a machine the developing players did not initiate these sub-components at the same time, compared to when they batted against a bowler. At this stage of learning it seems that batters have the required coordinative relationships between movement components, but are not yet able to finely adapt them in different performance contexts, showing less independence between the upper and lower extremities. Initiation of the backswing against the bowler occurred after ball release (drive: 0.06s; defence: 0.06s), and significantly later against the bowling machine (drive: 0.15s; defence: 0.14s). These data contradicted outcomes

of studies from more skilled batsmen (Renshaw et al., 2007). Although against the bowler backswing initiation occurred after ball release (0.12s), when skilled batters faced the bowling machine backswing initiation occurred around the point of ball release, suggesting that they had picked up non-specifying variables to regulate their batting actions. It was concluded that the batters may have used other information sources specific to practice task constraints involving use of ball projection machines to couple and initiate movement responses. This is a key difference between skilled and developing batters, which suggests that extended experience of practising against a bowling machine resulted in a major shift in information-movement coupling, as players searched for and relied on a non-specifying variable in a competitive performance environment.

Previous research has highlighted the importance of the organisation of the two-phases of bat swing, with skilled players being able to alter the ratio of backswing-downswing in the forward defensive stroke across different ecological task constraints (Renshaw et al., 2007). For developing batsmen there were practically no differences between the ratios, with both shorter backswings and downswings when facing a bowling machine. Batters controlled this bi-phase action by significantly limiting the height of the bat swing when facing the bowling machine when attacking and defending. Due to the reduction in the advanced information afforded by the bowling machine condition, developing batters tended to rely on a prospective control strategy during ball flight to adapt movement timings and responses. This strategy resulted in a reduction in the height of the backswing, to enable successful task performance. Similarly, due to the late initiation of the front foot movement, the step length during the bowling machine condition was significantly shorter. As Renshaw et al. (2007) observed this movement strategy resulted in the player being further away from the pitch of the delivery and more susceptible to late swing or deviation (Woolmer, Noakes, & Moffett, 2008). Analysis of the position of the head over the front foot in each condition

revealed no significant differences between practice task constraints due to wide variations. However, it was evident that the batters tended to play in a more upright stance against the machine. Observation of larger elbow and front knee angles at impact complimented the qualitative video and coaches' analysis, suggesting that the added temporal constraint when batting against the bowling machine resulted in significant spatial changes to the movement pattern. Under this condition batters played further away from their body (e.g. forward of the front pad, see Fig. 4), suggesting that they were attempting to reduce the distance between the bat and bounce point. As a result of these changes, there was a reduction in shot quality and batsmen were evidently not as balanced during the impact and follow-through.

Temporal and kinematic differences observed for the defensive and drive shots in the two different ecological conditions raised some issues about the perceptual abilities of non-expert batters. Previous research in fast ball sports using visual occlusion paradigms has shown that only experts are able to pick up pre-ball flight information from opponents' movement patterns (e.g., Müller & Abernethy, 2006; Müller et al., 2006). However, findings from our study suggested that batters at lower levels of skill development may be able to use the bowler's movements to guide their actions. First, the different backswing heights for the two shots suggested that batters were able to distinguish between a ball of good length that afforded a defensive shot, and a half volley which could be driven, very early in the delivery. Interestingly, when facing the bowling machine, although initiation began later due to the need to assimilate ball flight information, similar differences were observed in backswing height for both shots, although they were evidently shorter due to their later initiation. This interpretation is tentative, given that in temporal terms bat swing times were similar in the two conditions, but were longer in the bowler condition. This finding could be interpreted as batters adjusting their movements in a prospective manner and taking the bat higher as a result of picking up more ball flight information. Second, given that batters had no certainty

over the length of the upcoming delivery, their foot movements could be interpreted as identifying the point at which they made a decision about the length of the delivery (whether to advance forward for a forward defence or forward drive or to move backwards due to a shorter pitched delivery). In the bowler condition initiation took place 0.06s after ball release. It is noteworthy that laboratory-based tasks on young football players have demonstrated eye-foot reaction times that were much larger than this value (e.g. 0.3-0.4s, see Montes-mico, Bueno, Candel, & Pons, 2000), and visual reaction times in fast ball sports are considered to be in the region of 0.2s (see McLeod, 1987). These findings could be interpreted to suggest that the batters made up their minds on the eventual bounce point of the ball at a point in time either prior to or very close to ball release, proposing that non-experts could use information from a bowler's actions to guide movement. Conversely, the constraints of batting against the bowling machine meant that batters had to delay the initiation of the front foot movement until early ball flight information could be assimilated to determine ball length.

Changing the ecological constraints of practice and making it more representative in task design, by enhancing the availability of specific advanced information from a bowler's movements, resulted in major changes to the information-movement couplings of the batters. The results of this study are comparable with data reported by Renshaw et al., (2007) and help to extend our understanding of how movements are coupled to information in interceptive actions. The findings support previous suggestions of avoiding an over-reliance on bowling machines in practice at a developmental stage. Less-skilled batsmen displayed stable patterns of movement coordination, exemplified by the maintenance of the backswing and front foot movement coupling in both conditions. It is important at the control stage of learning that batsmen are able to identify the critical information sources and continue the process of perceptual attunement with specifying variables (Jacobs & Michaels, 2002; Dicks et al., 2008). This practice strategy requires specifying variables to be available for pick up by

learners at all times. Batting against a bowler permits established coordination patterns to be calibrated and finely tuned by the pick-up of specifying variables. This calibration process relies on the availability of representative task designs that accurately reflect performance environments (Dicks et al., 2008). The results of the present study are aligned with proposals of Beek et al. (2003), highlighting the importance of specificity of practice task constraints, particularly during specific developmental stages. The use of a bowling machine resulted in batters converging on nonspecifying variables, delaying the development and attunement to specifying variables (Araújo et al., 2007).

Our results suggested that use of a bowling machine not only changes available informational variables up until ball release (Bartlett, 2003), but also changes the nature of the delivery after ball release. We are not suggesting the complete removal of bowling machines from practice. Further research is needed to develop innovative methods to allow batters to undertake the volume of task specific practice required to develop perceptual skills (Weissensteiner et al., in press), while maintaining representative task designs. Batting against real bowlers supports the detection of specifying variables. However, as bowlers are limited to specific workloads (see Stretch & Gray, 1998, cited in Woolmer et al., 2008) research into representative video-based simulations may be more beneficial than using bowling machines. Research is required to assess the information-movement couplings established when using video-based simulation training. A representative video-based training system would allow batsmen to practice in a safe environment, and could be used to speed up the development of perceptual and movement capabilities of players against fast bowling. We have demonstrated that due to changes in the information movement couplings, developing players are more attuned to advanced information sources than previously believed. Future research is required to discover the exact sources of information that can be picked up to regulate actions at different stages of the skill pathway in cricket batting.

References

- Abernethy, B. & Russell, D. G. (1984). Advanced cue utilisation by skilled cricket batsmen. *Australian Journal of Science and Medicine in Sport*, *16*, 2-10.
- Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception*, *30*, 233-252.
- Araújo, D., Davids, K. & Passos, P. (2007). Ecological validity, representative design and correspondence between experimental task constraints and behavioural settings. *Ecological Psychology*, *19*, 69-78.
- Bartlett, R. (2003). The science and medicine of cricket: An overview and update. *Journal of Sports Sciences*, *21*, 733-752.
- Bartlett, R. (2007). *Introduction to Sports Biomechanics: Analysing Human Movement Patterns* (Second Edition). London: Routledge.
- Beek, P. J., Jacobs, D. M., Daffertshoffer, A. & Huys, R. (2003). Expert performance in sport: Views from the joint perspectives of ecological psychology and dynamical systems theory. In J. L. Starkes and K. A. Ericsson (Eds.), *Expert performance in sport: Advances in research on sport expertise* (pp.321-344). Champaign, IL: Human Kinetics.
- Davids, K., Button, C. & Bennett, S. (2008). *Dynamics of Skill Acquisition: A Constraints-led Approach*. Champaign, IL: Human Kinetics.
- Davids, K., Renshaw, I. & Glazier, P. (2005). Movement models from sport reveal fundamental insights into the coordination process. *Exercise and Sport Science Reviews*, *33*, 36-42.
- Davids, K., Button, C., Araújo, D., Renshaw, I. & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behaviour in human movement systems. *Adaptive Behaviour*, *14*, 73-95.

- Dennis, R. J., Finch, C. F. & Farhart, P. J. (2005). Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *British Journal of Sports Medicine*, 39, 843-846.
- Dicks, M., Davids, K. & Araújo, D. (2008). Ecological psychology and task representativeness: implications for the design of perceptual-motor training programmes in sport. In Y. Hong & R. Bartlett (Eds.), *Handbook of Biomechanics and Human Movement Science* (pp. 129-139). New York: Routledge.
- Fajen, B. R., Riley, M. A. & Turvey, M. T. (in press). Information, affordances and the control of action in sport. *International Journal of Sport Psychology*.
- Gibson, A. P. & Adams, R. D. (1989). Batting stroke timing with a bowler and a bowling machine: A case study. *Australian Journal of Science and Medicine in Sport*, 21(2), 3-6.
- Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.
- Houlston, D. R. & Lowes, R. (1993). Anticipatory cue-utilization processes amongst expert and non-expert wicketkeeper in cricket. *International Journal of Sport Psychology*, 24, 59-73.
- Jacobs, D. M. & Michaels, C. F. (2002). On the paradox of learning and realism. *Ecological psychology*, 14(3), 127-140.
- McLeod, P. (1987). Visual reaction time and high speed ball games. *Perception*, 16, 49-59.
- McLeod, P. & Jenkins, S. (1991). Timing accuracy and decision time in high speed ball games. *International Journal of Sport Psychology*, 22, 279-295.
- McMorris, T., & Colenso, S. (1996). Anticipation of professional soccer goalkeepers when facing right- and left-footed penalty kicks. *Perceptual and Motor Skills*, 82, 931-934.

- McRobert, A. & Tayler, M. (2005). Perceptual abilities of experienced and inexperienced cricket batsmen in differentiating between left hand and right hand bowling deliveries. *Journal of Sports Sciences*, 23(2), 190-191.
- Montagne, G. (2005). Perspective control in sport. *International Journal of Sport Psychology*, 36, 127-150.
- Montagne, G., Cornus, S., Glize, D., Quaine, F. & Laurent, M. (2000). A perception-action coupling type of control in long jumping. *Journal of Motor Behavior*, 32, 37-43.
- Montes-mico, R., Bueno, I., Candel, J. & Pons, A. M. (2000). Eye-hand and eye-foot visual reaction times of young soccer players. *Journal of the American Optometric Association*, 7 (12), 775-780.
- Müller, S. & Abernethy, B. (2006). Batting with occluded vision: An in situ examination of the information pick-up and interceptive skills of high- and low-skilled cricket batsmen. *Journal of Science and Medicine in Sport*, 9, 446-458.
- Müller, S., Abernethy, B. & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *The Quarterly Journal of Experimental Psychology*, 59(12), 2162-2186.
- Mullineaux, D. R., Bartlett, R. M. & Bennett, S. (2001). Research design and statistics in biomechanics and motor control. *Journal of Sports Sciences*, 19, 739-760.
- Newell, K. M. (1985). Coordination, control and skill. In D. Goodman, R. B. Wilberg, & I. M. Franks (Eds.), *Differing perspectives in motor learning, memory and control* (pp. 295-317). Amsterdam: Elsevier Science.
- Penrose, J. M. T. & Roach, N. K. (1995). Decision making and advanced cue utilisation by cricket batsmen. *Journal of Human Movement Studies*, 29, 199-218.
- Regan, D. (1997). Visual factors in hitting and catching. *Journal of Sports Sciences*, 15, 533-558.

- Renshaw, I. & Fairweather, M. M. (2000). Cricket bowling deliveries and the discrimination ability of professional and amateur batters. *Journal of Sports Sciences*, 18, 951-957.
- Renshaw, I., Oldham, A. R. H., Davids, K. & Golds, T. (2007). Changing ecological constraints of practice alters coordination of dynamic interceptive actions. *European Journal of Sport Science*, 7(3), 157-167.
- Schöllhorn, W. (2003). Coordination dynamics and its consequences on sports. *International Journal of Computer Science in Sport*, 2, 40-46.
- Stretch, R. A., Bartlett, R. & Davids, K. (2000). A review of batting in men's cricket. *Journal of Sports Sciences*, 18, 931-949.
- Stretch, R., Buys, F., Du Toit, E. & Viljoen, G. (1998). Kinematics and kinetics of the drive off the front foot in cricket batting. *Journal of Sports Sciences*, 16, 711-720.
- Van der Kamp, J., Rivas, F., Van Doorn, H. & Savelsbergh, G. (2008). Ventral and dorsal contributions in visual anticipation in fast ball sports. *International Journal of Sport Psychology*, 39, 100-130.
- Weissensteiner, J., Abernethy, B., Farrow, D. & Müller, S. (in press). The development of anticipation: A cross-sectional examination of the practice experiences contributing to skill in cricket batting. *Journal of Motor Behavior*.
- Williams, A. M., Davids, K. & Williams, J. G. (1999). *Visual perception & Action in Sport*. London: E & FN Spon.
- Withagen, R. (2004). The pickup of nonspecifying variables does not entail indirect perception. *Ecological Psychology*, 16(3), 237-253.
- Woolmer, B., Noakes, T. & Moffett, H. (2008). *Bob Woolmer's Art and Science of Cricket*. London: New Holland.

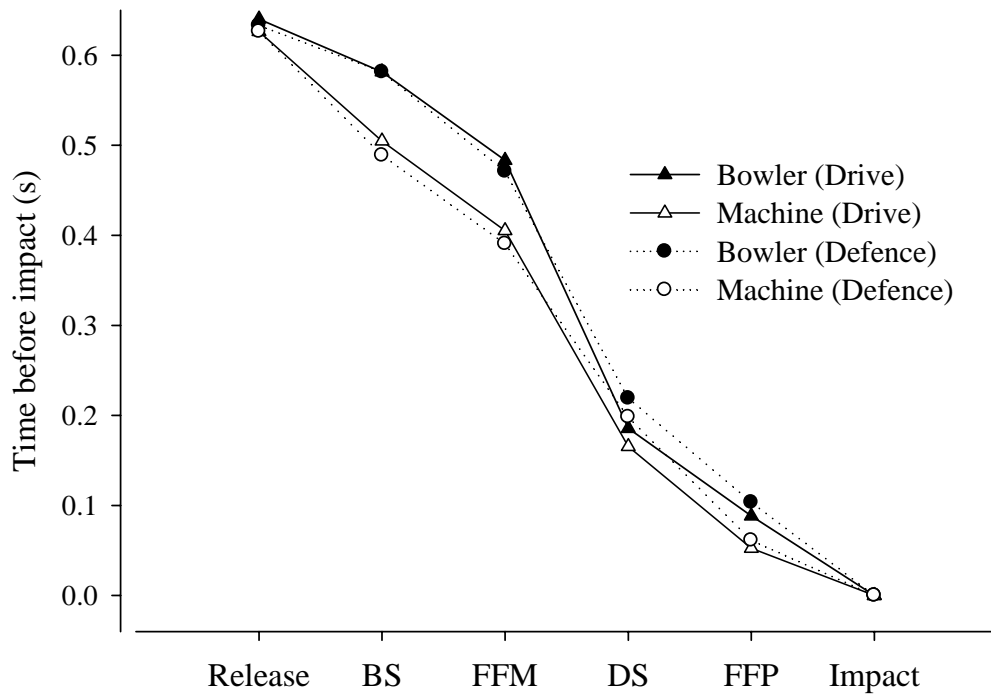


Fig. 1. Differences in the timing of key phases of the forward defensive and forward drive strokes in bowler and bowling machine conditions (BS: Initiation of backswing; FFM: Initiation of front foot movement; DS: Initiation of downswing; FFP: Front foot placement).

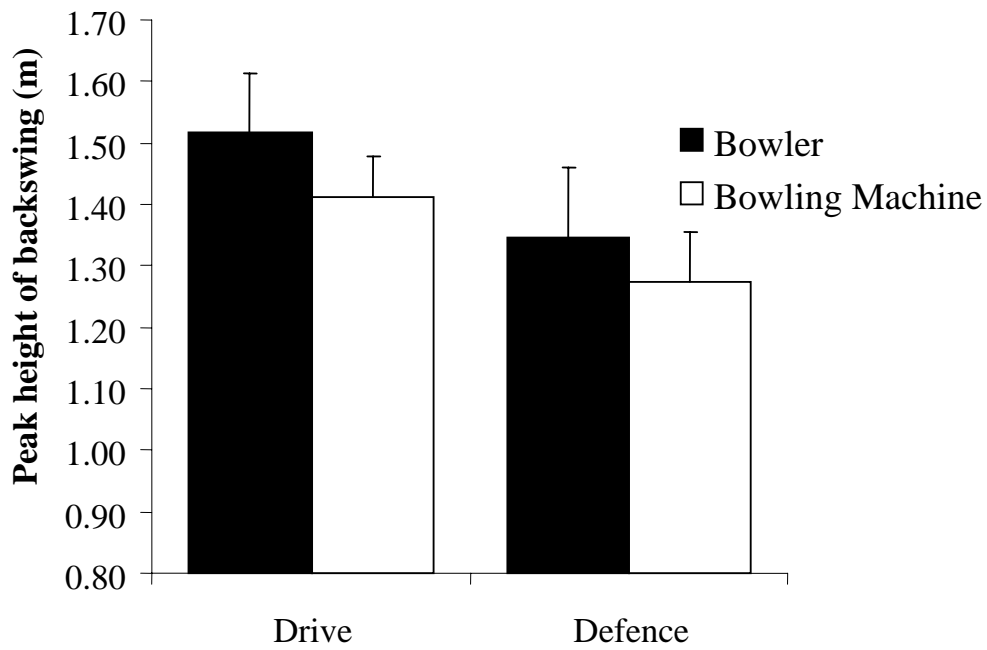


Fig. 2. Peak height of the backswing for batsmen (n=12) facing a bowler and bowling machine for the forward defence and forward drive.

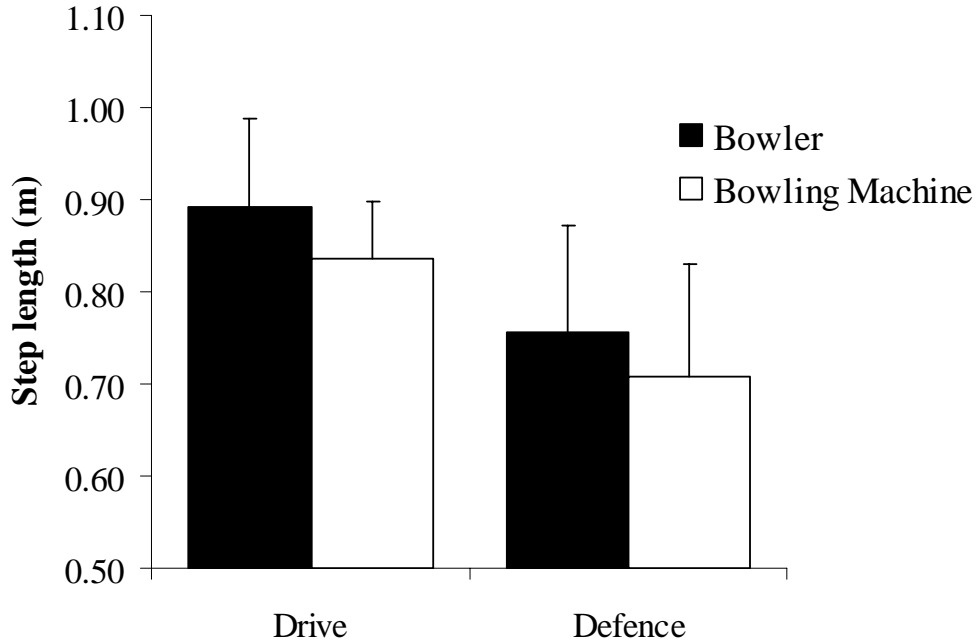


Fig. 3. Step lengths at front foot placement of the forward drive and forward defence, with batsman (n=12) facing a bowler and a bowling machine.



Fig. 4. Video stills highlighting the major differences in the batters' responses to a bowling machine (left) and a bowler (right).

Table 1. Joint segment angles (degrees) of the forward defensive stroke in both bowler and bowling machine conditions (means ± s).

	Front Elbow		Back Elbow		Front Knee	
Backswing initiation						
Bowler	135	± 20	108	± 20	166	± 8
Bowling Machine	140	± 14	113	± 18	167	± 7
		<i>p</i> <0.05		<i>p</i> <0.001		
		<i>r</i> = 0.36		<i>r</i> = 0.47		<i>r</i> = 0.03
Front foot initiation						
Bowler	124	± 23	92	± 23	156	± 6
Bowling Machine	130	± 15	98	± 21	160	± 6
		<i>p</i> <0.001		<i>p</i> <0.05		<i>p</i> <0.001
		<i>r</i> = 0.40		<i>r</i> = 0.37		<i>r</i> = 0.44
Downswing initiation						
Bowler	110	± 13	71	± 13	163	± 9
Bowling Machine	117	± 13	75	± 15	161	± 7
		<i>p</i> <0.001		<i>p</i> <0.001		
		<i>r</i> = 0.48		<i>r</i> = 0.42		<i>r</i> = 0.19
Front foot placement						
Bowler	110	± 18	87	± 20	166	± 8
Bowling Machine	120	± 19	94	± 18	168	± 6
		<i>p</i> <0.001		<i>p</i> <0.05		
		<i>r</i> = 0.46		<i>r</i> = 0.29		<i>r</i> = 0.20
Impact						
Bowler	127	± 20	112	± 20	163	± 10
Bowling Machine	131	± 23	120	± 18	167	± 7
				<i>p</i> <0.05		<i>p</i> <0.05
		<i>r</i> = 0.22		<i>r</i> = 0.37		<i>r</i> = 0.25

Note: effect size, *r*; 0.10 = small effect, 0.30 = moderate effect, 0.50 = large effect