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Changing ecological constraints of practice alters coordination of dynamic interceptive actions

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Abstract

Ecological constraints of practice significantly affect the acquisition of functional information-movement couplings and learners need to converge on information-specifying perceptual variables. Consequently, prolonged and widespread use of ball projection machines for practice of interceptive actions may lack theoretical foundation because they afford information-specifying variables which are not present in competitive performance. To examine this issue, timing and coordination of the forward defensive stroke in cricket batting were examined in experienced batters under two typical practice task constraints: batting against a representative 'real' bowler (B) and a representative bowling machine (BM) (mean delivery velocity 26.76 m s^{-1} under both conditions). Results showed significant adaptation of coordination and timing under the different practice task constraints. For example, initiation of the backswing was later against a bowler and downswing was faster with a different ratio of backswing–downswing when batting in the BM condition (47%: 53%) compared to B (54%: 46%). Peak bat height differed under the two constraints (BM: 1.56±19.89 m and B: 1.72±10.36 m). Mean length of front foot stride was shorter against the BM (0.55±0.07 m) compared to B (0.59±0.06 m). Correlation between initiation of backswing and front foot movement was much higher against B (r=0.88) than BM (r=0.65). Results suggested that coaches should ensure opportunities for regular practice against 'real' bowlers, so that batters become attuned to the information available for pick up in those specific practice constraints. Projectile machines may be best used under special conditions in which coaches randomise the bounce point and deliver balls at slower speeds to allow batters to sample early ball flight before selecting shot responses.

Introduction

Skill in coordinating interceptive actions with respect to the environment is an important requirement of ball games, requiring many years of dedicated practice. The ecological constraints of ball games are characterised by the unique constraints of each individual performer and the specific task being performed, as well as the physical, social and cultural factors encompassing performance more broadly (see Araújo, Davids & Serpa, 2005; Araújo, Davids & Hristovski, 2006). Informational constraints of fast ball sports are a sub-set of these ecological constraints, related to the information available within the specific task being undertaken during performance or practice. In interceptive actions they include such variables as time-to-contact information from ball flight or advanced information sources available from opponents' movements (e.g., Tyldesley & Whiting, 1975; Abernethy & Russell, 1987; Regan, 1997).

Ecological psychologists view skilled performance in interceptive actions as predicated on the tuning of actions to changing informational constraints of the environment (e.g., Savelsbergh & Van der Kamp, 2000). For this reason, team ball games can provide useful movement models (e.g., hitting and catching) for studying how processes of perception and movement support the coordination of actions with respect to events in dynamic environments (e.g., Davids, Renshaw & Glazier, 2005; Davids, Button, Araújo, Renshaw & Hristovski, 2006). From previous research in ecological psychology it has become apparent that information-movement couplings form the basis of interceptive actions. Information constrains movements and perception has been defined as the detection of information (Gibson, 1986). An important experimental strategy in previous work on interceptive actions has been to manipulate properties of environmental information in order to observe any changes in participants' organization of movement responses, as expressed in movement kinematics. The assumption is that any changes to observed movement kinematics are likely due to experimental manipulations of perceptual variables purported to act as information specifying or constraining action (Jacobs & Michaels, 2002). In recent years, empirical support has increased for prospective control of interceptive actions in which various information sources are coupled to movements and used to continuously regulate even the most rapid of interceptive actions (Beek, Dessing, Peper & Bullock, 2003a; Montagne, 2005). For example, catching experiments have shown that, even when the hand is pre-positioned in the spatial trajectory of an approaching ball, it is initially moved away before 'reversing' back to the correct line of flight in order to intercept it (e.g., Montagne, Laurent, Durey & Bootsma, 1999). Such 'movement reversals' are not superfluous, and have been construed as evidence of performers creating visual information in order to couple their hand movements continuously with ball flight information.

Specificational information sources for constraining action are regularities that can be picked up from particular performance environments and an important aim of practice is to help learners to detect constraining variables from non-constraining variables surrounding them. Constraining variables provide better information to support actions, whereas non-constraining variables offer less support to performers (Araújo, Davids & Passos, 2007). Since perception is specific to the environmental properties uniquely constraining each performance situation, it follows that changing the informational constraints of practice can deeply influence the movement behaviours that emerge (Beek et al., 2003b). According to Jacobs & Michaels (2002), the role of practice is to educate the attention of learners by facilitating the pick-up of constraining perceptual variables rather than non-constraining (less relevant) variables. As a result of practice, learners shift from picking up non-constraining variables and converge on constraining variables. Changes in movement kinematics would likely be observed when key perceptual variables were manipulated, indicating the information specifying or constraining action (Jacobs & Michaels, 2002).

Therefore, an important question concerns how altering the perceptual information available in practice environments constrains performance of interceptive actions. For example, in ball games such as baseball, tennis, field hockey and cricket, ball projection machines are useful tools in aiding practice strategies of task decomposition which allow a specific movement, such as a batting action, to be practised away from the constraints of a competitive game. This device allows an accurate and stable projection of balls to learners practising movements such as volleys at the net in tennis and the cricket strokes in nets. Since the principle of information-movement coupling signifies that informational constraints need to be preserved in relation to actions during practice, how does the use of ball machines influence the movement patterns that emerge during practice? Indeed, a number of studies of interceptive actions, including previous research on cricket batting, have suggested that experienced performers use pre-ball flight information in order to constrain movements (e.g., Williams, Davids & Williams, 1999). In sports like baseball and cricket, the ability to utilise information from a pitcher or bowler's body action patterns is considered an important determinant of expert performance in batting (e.g., Renshaw & Fairweather, 2000).

Of relevance to this study, research has shown that when skilled players bat against medium pace or fast bowlers they are able to predict the 'length' (bounce point) of the ball prior to observing flight, based on only viewing a bowler's action (Abernethy, 1981; Penrose & Roach, 1995). This learned ability provides them with a temporal advantage over their less skilled counterparts. Professional batters are able to exploit additional available perceptual degrees of freedom by coupling batting movements to key sources of information including ball flight information. Conversely, less experienced players gain little advantage from available body information of bowlers suggesting only a coupling to ball flight information (Renshaw & Fairweather, 2000; Renshaw, Fairweather, Oldham & Rotheram, 2003).

Renshaw & Fairweather (2000) found that occluding ball flight information did not disadvantage cricket batters, although pre-flight information from body orientation and limb segments of bowlers did influence batting performance. Therefore, it is unclear whether performing interceptive actions against projectile machines might constitute a valid method of practice since pre-flight information from a feeder's (e.g., bowler/thrower/pitcher/server) actions is not available and flight information does not seem to be used to any great extent. Theoretically, the key question is whether practising with ball machines can actually lead to the formation of inappropriate information-movement couplings for batting. Although some (e.g., Bartlett, 2003) have questioned whether the use of ball machines might constitute artificial practice constraints compared to batting against a real bowler in cricket, it is unclear from existing research whether the use of ball projection machines during practice specifically constrains the timing of movement coordination.

Research on Cricket Batting: Implications of Different Ecological Constraints

To examine this question one might consider the forward defensive stroke in cricket batting as a suitable task vehicle as it occurs in a single plane of movement allowing 2-d analysis (see Stretch, Buys, Dutoit & Viljeon, 1998; Gibson & Adams, 1989). The forward defensive is a complex movement which has been broken down by biomechanists into two phases: the back lift and stance, and the downswing to impact. Stretch et al. (1998) looked at body segment angles and movement initiation times during various stages of the forward defence. They reported mean data showing that, during the back lift, the front elbow was flexed to 142^{o} and the back elbow to 145^{o}. During the stride and downswing phase to impact, Stretch et al. (1998) found that front foot movement occurred 0.64 s pre-impact followed by the downswing of the bat 0.38 s pre-impact, with front foot placement taking place 0.15 s prior to impact. Stretch et al. (1998) also measured mean segment angles at the front and back elbow and front and back knee during the different phases of the stroke.

With respect to questions over the practice role of ball machines, some significant differences in timing of the forward defensive stroke by an international cricketer were reported by Gibson & Adams (1989) under two different task constraints: (i) when facing a fast-medium bowler; and (ii), when batting against a bowling machine set to the same speed. They found that, against a bowler, the batsman initiated the back swing at a consistent time before ball release. The bat was lifted slowly, held at the top of the bat swing and then the downswing was performed while completing the front foot movement. However, when facing the bowling machine, the back lift began at widely varying times, with the front foot movement starting before the back swing was completed. The back swing was held briefly at the top of the movement for a comparatively shorter period of time, the downswing was faster and the front foot movement was completed at around the start of the downswing. The early movement of the front foot against the bowling machine occurred much earlier than against the bowler, and is a somewhat surprising finding given the absence of information from a bowler's action. Gibson & Adams (1989) concluded that differences in stroke timing and foot movement timing suggested that the tasks are quite different in terms of the batsman's use of spatial and temporal information. However, given the very early movements of the batter prior to ball release it is unclear if these differences were actually due to the constraints of each task (i.e., batting against the bowling machine or bowler), or were a function of their specific experimental set-up (i.e., the early foot movements in the bowling machine condition may have been due to the fact that the batters knew the bounce point of the ball prior to delivery of the ball). Additionally, it was unclear whether the performer in their case study had any experience of playing against bowling machines and a question remains whether these interesting observations of one international player can be generalised to less elite performers.

In summary, theoretical ideas from ecological psychology, allied to biomechanical analyses of batting in cricket raise some questions over use of ball projection machines as a methodology for acquiring coordination patterns. The ecological constraints of batting against a bowler are very different from batting against a bowling machine, particularly differing in the informational constraints that can be used to gear actions. For this reason, the aim of this study was to examine if practising under the two different task constraints resulted in differences in timing and coordination of the forward defensive shot. Specifically, it was predicted that, in the bowling machine condition (when batters do not know in advance whether they have to step forward or back to play the ball) the absence of information from the bowler's action would result in batters having less time to organize their responses, leading to a later, shorter stride. However, in an attempt to offset the reduced time availability from ball release to bat contact, it might be expected that the batter would initiate his backswing earlier, followed by a lower backswing and faster downswing. In line with the observations of Gibson & Adams (1989), we expected greater variability in the initiation of the backswing when batters are unable to couple their backswing to bowling action information, leading to attempts to link this movement to the emergence of the ball from the bowling machine. A consequence of the predicted changes in the initiation times of foot movements and backswing would be reflected in a change in the coordination between upper and lower body.

Method

Participants

Four right handed batsmen (mean age=21±1 yrs, body mass=80.4±12 kg) who played in Premier League competitions in the U.K were participants. These leagues represent the highest standard available to non-professional cricket players and as such we categorised the batters as of high intermediate standard. All were selected because they had not faced the bowler in this study before and had used bowling machines of the same design as the one in this study as a regular part of their practice programs. All batters completed informed consent prior to starting the study. Ethical clearance was provided by a university ethics committee.

Apparatus and camera set-up

Filming took place at a cricket school which had a standard indoor cricket batting surface. The bowler was representative of right arm medium pace bowlers of equivalent performance standard to the batters (i.e., Premier League standard). He was selected as his bowling action was deemed to be representative of the typical bowling action of medium pace bowlers identified in the cricket coaching literature (Andrew, 1986). Verification of action similarity was provided by two English Cricket Board Level 2 coaches. Mean bowling speed was calculated using a speed gun (Speed Check. Tribar Industries, Canada) enabling us to calibrate the bowling machine (BOLA, Stuart and Williams, UK) to an equivalent speed (26.76±1.04 m s^{-1} for the bowler and 26.76±0.84 m s^{-1} for the bowling machine). The bowling machine selected for use is a very common machine used in practice at different levels of cricket performance from club-level to international class. It was set up so that the ball was delivered from the same release height as the bowler (2.30 m). The same type of balls (Bola cricket ball) was used in both conditions to ensure that the bounce remained consistent throughout the study. Batsmen were filmed from a side-on position. A camera (Sony

DCRTVR 900E) was placed 13.5 m from the batsman with the plane of motion perpendicular to the batting crease and at right angles to the movement direction of the forward defensive shot using the 3-4-5-triangle method. A telephoto zoom lens brought the performer's image to the required size. Frame rate was set at 60 Hz to avoid aliasing (Plagenhoef, 1971). Calibration occurred with a reference marker of known length (one metre rule) recorded in the same plane in which the participants were filmed. A split-image filming device was used to capture the point of ball release as well as the image of the batsmen.

Data Collection and selection of bowler and bowling machine deliveries

Before filming, markers (1 cm) were placed on selected body joint locations using standardized marker positions. Segment markers were placed on the foot (great toe), ankle (ankle protector of the pad), knee (knee role on pad), hip (greater trochanter of the femur), shoulder (greater tubercle of the humerus), elbow (lateral epicondyle of the humerus) and wrist (head of the ulna). Further markers were placed on the bat (handle and bottom edge nearest to the camera). This set-up enabled us to record segment angles at the knee and elbow joints, and to calculate bat swing timings, bat displacement and height of the backswing, and front foot placement. Batters faced balls delivered by the bowler and the bowling machine, in counterbalanced sequence to prevent order effects. The bowler was instructed to bowl as if in a usual practice session. Typically, bowlers, such as the participant in this study, aim to bowl 'accurately' forcing the batter to play a forward defensive shot as often as possible, but also occasionally forcing him/her to play off the back foot (once or twice per over). To reflect this tactic, when facing the bowling machine the bounce point of deliveries was manipulated (in a similar frequency) so that the task constraints of batting remained as similar as possible between the bowler and bowling machine conditions. The randomization of the bounce point was also essential in order to prevent batters from knowing in advance the shot they would be required to play. This randomization process was achieved by the feeder subtly altering the angle of ball release by pushing down or pulling up a horizontal handle on the back of the machine. The handle was obscured so that the batsman could not see the feeder changing the angle of the release and was unaware of what the bounce point would be for any specific ball. Selection of shots for analysis was based on strict criteria to ensure similarity of ball characteristics from the two different information sources. To provide consistency between deliveries in the two conditions, and to be deemed valid for use in the study, all balls were required to land on the line of the stumps (width = 22.86 cm) and within a vertical area of 30 cm. This area was selected so that the most appropriate shot response to a ball landing in this area would be the forward defensive shot. When facing the bowler the batters could see the whole of the bowler’s run-up. When facing the bowling machine, a standardised pre-delivery routine (as recommended by the manufacturer’s instructions) was used to ‘cue-in’ the batsmen. The ball feeder stood on a box behind the machine and held the ball up high at arms length. He then gained eye contact with the batsman to make sure he was ready. The feeder then slowly lowered his hand and placed the ball into the machine from above. Inside the machine the ball was then “forced” between two rotating wheels. After a short delay the ball emerged from the front of the machine. As the ball is forced between the wheels of the machine an audible “thud” can be heard by the batsman.

Data Analysis

Thirty two forward defensive shots, consisting of four deliveries each under bowler and bowling machine conditions from each batter, were selected for analysis based on the selection criteria identified earlier. On average it took between 8-12 shots to acquire the four shots from each batter in each condition to avoid providing the batsmen with stereotyped ball deliveries. As highlighted above some deliveries forced the batter to play off the back foot (2-

3) or did not land in the designated landing zone (2-5), but were not selected for analysis. Data were digitized using SIMI Motion system (version 6). Digital low pass filtering (6 Hz) was used to remove, or filter, high-frequency noise from the data. We digitized at a number of key phases of the forward defensive shot including: (i) at ball release; (ii) initiation of backswing; (iii) front foot movement; (iv) downswing; (v) placement of front foot; and (vi), at bat-ball impact. Key phases were identified from the first frame that an event was observed. For example, ball release was taken as the first frame after the ball left the bowler's hand, initiation of the front foot movement as the first frame after the foot had lifted off the ground and so on. This protocol allowed us to examine relative timings of the sub-components of the shot and the movement kinematics of the key body parts.

Statistical Analyses

To determine the relative timing between the sub-phases of the stroke in the two conditions we calculated means and standard deviations of the initiation and placement of the front foot and the initiation of backswing and downswing. Additionally, we measured backswing height and stride length and speed. Analysis methods were formulated with the goal of identifying large robust effects for discussion from an array of dependent variables. Bonferroni corrected Wilcoxon signed rank tests were employed for pairwise comparisons of each dependent variable. This decision was made with the following issues in mind. The segment angle data were drawn from a connected multi-link system and therefore highly correlated. The temporal data were co-dependent by virtue of being based on successive intervals. The sample to cells ratio was low and normality of data could not be assumed. In this way, data violated parametric assumptions necessary for MANOVA or standardised repeated measures ANOVA. Wilcoxon's tests were adopted as a conservative non-parametric alternative. Furthermore a pairwise approach accommodated the co-dependent nature of the data. In order to obtain an estimate of relative magnitude of significant effects, Cohen's *d* was also calculated for each comparison. Effect size has been proposed as an alternative to inferential statistics as it provides an estimate of meaningful differences, since it quantifies the magnitude of the difference between variables in an experiment (Mullineaux, Bartlett & Bennett, 2001). In this case effect size analysis was undertaken with the goal of identifying in relative terms the largest difference between variables, something that cannot be achieved by statistical significance testing alone. The effect size analysis should however be interpreted with care as *d* is parametrically based and still prone to familywise error.

Results

Temporal differences of the forward defensive under different task constraints

To examine potential differences due to the different task constraints, we identified the time of initiation of (i) backswing; (ii) front foot movement; (iii) downswing; and (iv), planting of the front foot (see Figure 1) Observed major differences occurred in relation to the two phases of the backswing. When facing the bowling machine, batters began the backswing much earlier than when the facing the bowler (BM: 0.02±0.10 s v B; 0.12±0.04 s[1], z=-2.415, p=0.016, ES=1.49). Similar differences were observed for the timing of the downswing phase which commenced earlier when facing the bowling machine compared to the bowler (BM: 0.32 ± 0.04 s v B: 0.41±0.03 s, z=-3.410, p=0.001, ES=2.46). In comparison, front foot movements were both initiated and planted at similar times in the two conditions, with movements beginning slightly earlier when batting against the bowler (B: 0.14±0.03 s v BM: 0.16±.0.04 s). Finally, the timing of the foot placement was later when facing the bowler (B: 0.55±0.05 s v BM: 0.53±.0.05 s). These minor differences resulted in a longer total time length to complete the stride when facing the bowler (0.41±0.04 s) compared to the machine (0.37 s ±0.05 s). To complement our temporal data we measured the length of the stride and found that it was shorter when facing the bowling machine compared

[1] In the data collection bat-ball contact was measured as 0 s, for simplicity we have reported the temporal data taking ball release as 0 s.

to the bowler (BM: 0.55±0.07 m v B: 0.59±0.06 m). In addition, the speed of the front foot movement was faster when facing the machine (BM: 1.69 ms^{-1} v B: 1.53 ms^{-1}). Finally, we measured peak height of the backswing, observing a higher and more consistent peak backswing in the bowler condition (BM: 1.56±0.19 m B: 1.72±0.1, ES=0.71).

-------------------------------------Insert figure 1 here---

We next examined temporal differences in the two phases of the bat swing in more detail. We observed that the different task constraints led to a change in the total time length from backswing initiation to impact, and resulted in a much shorter bat swing time when facing the bowler (B: 0.54 v BM: 0.64 s). Interestingly, despite the backswing starting earlier when facing the bowling machine, backswing duration was similar in the two conditions (B: 0.29 v BM: 0.30 s). However, downswing was faster against the bowler (B: 0.25 v BM: 0.34 s). This difference is highlighted in the ratio of the backswing to the downswing component of the bi-phasic action between the two conditions. The ratio of backswing–downswing is 47%: 53% in the bowling machine condition and 54%: 46% in the bowler condition (see Figure 2).

--Insert figure 2 here--

Coordination Differences

We measured knee and elbow angles at each of the temporal phases identified previously and, given the temporal differences between the two conditions, noted a number of differences (see Figure 1 and Table 1). The main differences were due to changes in the coordination of arm movements (i.e., the bat swing) and movements of the lower body (i.e., front foot movements). Against the bowler, batters started backswing and front foot movements at very similar times, whereas against the machine, backswings were started close to the time of ball release. This finding implied that, at front foot initiation, the bat was already moving back and up (reflected by elbow angle differences at ball release and front foot initiation, and front knee angle differences at backswing initiation). It is also worth noting the higher standard deviations for both elbow angles in the machine condition at ball release (see Table 1). These differences in timing meant that batters were at different stages of their stride when the downswing started. However, differences were also apparent in elbow angles. These differences were due to batters swinging the bat back higher when facing the bowler than against the machine (B: 1.72±10.36 m v BM: 1.56±19.89 m) (see Figure 3). At front foot placement, elbow differences showed that the downswing was nearer to completion when facing the machine than against the bowler. At impact, elbow angles of greater magnitude were observed in the machine condition compared to the bowler condition.

---------------------------------Insert Table 1 here--

Coordination of front foot initiation and backswing

In the bowler condition we found a large correlation (r=0.88, p=0.001) for these movement landmarks, while against the machine the relationship was lower (r=0.65, p=0.006). Coefficients of determination revealed that the explained variance in the data due to different task constraints was 77% for the bowler condition and 42% for the bowling machine condition. Clearly, changing the ecological constraints of practice by removing the availability of information from the bowler's action in the bowling machine condition had a major impact on the ability of the batters to couple backswing and front foot movement.

-------------------------------------Insert figure 3 here---

Individual Analyses

Given the logistical difficulty of accessing large samples of experienced participants in this type of study, an important question concerns whether the findings from four batters enable us to make generalisable conclusions**.** It is necessary to understand whether the mean trends reported between the bowler and bowling machine conditions hold for all participants or only for some of the participants. The results showed that, in general terms, each of the batter's displayed findings that reflected the group data. In relation to the front foot movement we observed that all of the batters took a longer stride length against the bowler. For three of the batters (2, 3 and 4) this outcome also translated into longer, slower strides.

For bat swing patterns, individual analyses highlighted the earlier, yet more inconsistent backswing initiation times for 3 of the batters (2, 3 and 4) against the bowling machine. Batter One was an exception here using a strategy of late backswing initiation against both bowler and bowling machine (B: 0.52 s v BM: 0.49 s). However, the variability of his backswing was much higher when facing the bowling machine (0.13 s v 0.04 s). Downswing initiation was earlier against the bowling machine for all of the batters. Finally, we examined how use of the bowling machine affected the coupling of backswing to front foot movement for each of the batters. When we examined the mean differences between the two phases for each batter, results revealed that the time differences were always greater when facing the bowling machine (ranging from 0.03 s for Batter One to 0.14 s for Batter Three).

Discussion

The aim of this study was to investigate whether the different ecological constraints of batting against a representative bowling machine compared to batting against a representative medium-pace bowler would result in differences in the timing and coordination of the forward defensive shot in cricket batting. We wanted to examine the specificity of the information-movement couplings adopted by performers of striking actions under changing ecological constraints, represented by variations in perceptual information available from delivery of a projectile.

We observed that batting against the bowling machine, as opposed to the bowler, led to a re-organization of the coordination and timing of the forward defensive shot by the sample of batters. Although there was no direct empirical evidence to suggest that the batters in this particular study were capable of picking up advanced information from the bowler's movement patterns[2], it was clear that they adopted a functional strategy which reflected a reliance on ball flight information only. These differences seem to have been mainly due to changes in the organisation of the two-phases of the bat swing: backswing and downswing, allied to differences in duration of the front foot movement. The first point to note is that an overall difference in the two conditions was observed for the ratio of backswing to downswing in the stroke. In the bowling machine condition the duration of backswing was shorter than the downswing (47%: 53%), whereas, in the bowler condition, backswing was proportionally longer than the downswing (54%: 46%). A significant difference was also found between the initiation points of the backswing and downswing. When batting against the bowler, the backswing was initiated after the ball had been released (0.11 s). In contrast, against the bowling machine, backswing initiation varied greatly, but was based around the time the ball emerged from the bowling machine. It appears that the ecological constraints of batting against a bowling machine directed the batters towards a strategy of predicting when the ball would appear from the machine's projection mouth and to couple backswing to this point in time. It is worth noting that although the batters do not have advance cues from a bowler to use in the BM condition, they clearly have other advance cues such as the standardised pre-delivery routine and auditory thud of the ball emerging from the machine. As such they may have attempted to anchor their backswings to these information sources under these practice task constraints. Interestingly, despite the later start of the backswing, the duration of this phase was similar in both conditions. At the top of the backswing we found that there was no "hold", as reported by Stretch et al. (1998), but not by Gibson & Adams (1989). A final point with regard to the backswing relates to peak backswing height. Although no statistically significant difference in peak backswing height was observed, a moderate effect size (0.71) suggested that batters adopted a higher backswing in the bowler

[2] However, in the introduction we noted previous research demonstrating how skilled batters can pick up and use advance information from bowlers' actions (e.g., Abernethy, 1981; Penrose and Roach, 1995; Renshaw and Fairweather, 2000). We had no reason to assume that our sample of skilled batters was not representative.

condition (see Figure 3). Downswing commenced at 0.34 s pre-impact against the bowling machine and 0.25 s against the bowler.

Taken together these findings suggest that practising under the ecological constraints of bowling machines can lead to the development of coordination patterns and timing that differ considerably when batting against a real bowler. It has been known for some time that a key feature of striking actions is the development of stable movement organisation (e.g., Hubbard & Seng, 1954) and a consequence of practising extensively against the bowling machine is a lack of variation to practice the adaptive behaviour needed under competitive performance conditions. Furthermore, batting against the bowling machine led to technically inferior stroke production. The earlier downswing time when facing the bowling machine signified that less ball flight information could be perceived before shot completion. This observation signifies that in order to prospectively control action against late ball movement (in the air or off the pitch) the batter moved his bat down in a more conservative manner (i.e. more slowly) than when facing the bowler (see Land & McLeod, 2000; Montagne, 2005). Similarly, the shorter step when facing the machine meant that the batter did not get as close as possible to the bounce point of the ball, thus failing to limit the amount of any possible "sideways" deviation of the ball after it pitched. The need to 'see the ball early, but play it late', while attempting to place the front foot as near as possible to the landing point of the ball, is a key point when playing the forward defensive shot (Boycott, 1994). As such, the combined technical errors that were observed in the bowling machine condition would increase the possibility of batters edging a catch or being hit on the front pad and being given out 'leg before wicket'.

When we compared our results with previous findings by Gibson & Adams (1989) we concluded that although there were some similarities, generally our findings were somewhat different. In particular there is some ambiguity to be resolved in future research over the view that batting against the bowling machine provides more certainty, thus enabling earlier initiation of front foot movement. Our study showed that batting against bowling machines resulted in batters having to search for appropriate movement solutions since the information from the bowler's run-up and action was not available. An interesting issue for further study concerns the rate of adaptation of stable movement patterns by batters after extensive practice against a bowling machine (e.g., warming up against bowling machines in the nets prior to competitive performance). Our results supported Gibson & Adams' (1989) findings that backswing initiation was more consistent against the bowler, but was much more varied against the bowling machine. However, whereas the international player in their study initiated his backswing before ball release, we found that 3 out of 4 of our less elite sample of batters initiated their backswing after the point of ball release. Additionally, in contrast to data reported by Gibson & Adams (1989) we found that peak height of the backswing was reached earlier in the bowling machine condition. Also, whereas Gibson & Adams (1989) found that the downswing against the bowler occurred earlier, we observed that downswing was initiated earlier against the bowling machine. A further difference was that our batters did not 'hold' their backswing for any period of time before initiating the downswing. In terms of front foot movements, Gibson & Adams' (1989) data showed that front foot movements against the bowling machine occurred much earlier than when facing the bowler. However, we found that there was no difference in initiation of front foot movement with front foot initiation occurring after ball release. Significantly, our findings showed that front foot movement was closely coupled to backswing in the bowler condition, while this coupling was weakened in the bowling machine condition. Clearly, our study has enabled us to build on the work of Gibson & Adams (1989) and to add some additional insights into batting under different practice task constraints in cricket. Our data suggested the need for further research with a larger sample, varying in skill level, to provide a more detailed comparison of the forward defensive shot when facing a bowler and bowling machine. An important focus for future research could be to examine the effects of varying the length of ball deliveries to batters, since it is not clear from Gibson & Adams' (1989) study whether their participant knew before the ball was bowled what shot he would be playing. This possibility could account for observations of early foot movement and the increase in 'certainty' that Gibson & Adams (1989) discussed in their paper. Our work set out to reconstruct specific variations in ecological task constraints of practice and the batters in our study did not know in advance what the length of the ball would be (in both conditions). Further work is needed to elucidate the effects of varying the bounce point of the delivery on batting performance under different practice task constraints.

Theoretically, the findings of this study allow us to make some important points on the nature of predictive and prospective control strategies which may be adopted by performers. We found that the constraining perceptual information available in the ecological constraints of the task led to the emergence of variable but functional movement solutions. In an interceptive action like cricket batting, perceptual information has been shown to play a significant role in continuously constraining the movement as it unfolds. Clearly, the perceptual variables that specify information for action need to be carefully considered in sport practice since convergence on non-specifying perceptual variables (e.g., those from a projectile machine) may hinder the successful acquisition and performance of interceptive actions (Beek et al., 2003a).

These ideas on modeling performance of interceptive actions have some important implications for developing perceptual skills for cricket batting. Expert batters are able to utilise bowlers' actions in order to predict both the line and length of bowling deliveries and the type of spin put on the ball (Abernethy, 1981; Penrose & Roach, 1995; Renshaw and Fairweather, 2000). As such, expert batters are able to provide themselves with a temporal advantage, in that they are able to make stroke choice decisions at a relatively early stage of the bowling delivery. The absence of this information in the bowling machine condition signifies that the batter has to delay this decision while early ball flight information is assimilated. Thus, batters need to re-organise their movements in order to cope with this temporal constraint in practice. A key feature of expertise in cricket batting is learning to identify the specifying information from the body action movements of the bowler. Research has highlighted that in order to perceptually discriminate ball delivery types, high skilled batters are attuned to the relationship between critical segments within the bowling action (Müller, Abernethy & Farrow, 2006). Practice against real bowlers enables the pick up of constraining perceptual variables rather than non-constraining variables. In Gibsonian terms, the batter needs to become attuned to the affordances of the bowler's action (Gibson, 1986). To summarise, practising batting against bowlers will afford attunement to information from bowlers' actions and will support the acquisition of appropriate information-couplings for batting in competitive performance. Batting against bowling machines will result in attunement to early ball flight information, leading to information-movement couplings which may be consistent, but lack the adaptability needed against bowlers. Although, Bartlett (2003) highlighted that batting against a bowling machine is different than batting against bowlers, at least up until the release of the ball, our data suggest that batting against a bowling machine is also different *after* the release of the ball.

The practical implications of these data imply the need for specificity of training to be considered in designing practice of interceptive actions. According to Beek et al. (2003a) perceptual variables that remain too constant over practice are 'rendered useless' and should be avoided. They argued that an important aim of practice is for learners to converge on perceptual variables that will appropriately constrain action. They noted that when learners converge on variables that only weakly constrain action early in learning (i.e. non-specifying variables that allow a limited amount of performance stability) the formation of more functional information-movement couplings might be delayed. The implication is that practitioners need to determine strongly constraining perceptual variables from those that only weakly constrain movement during practice. This clarification will allow practitioners to understand whether learning may proceed more rapidly if weakly constraining variables are avoided in the learning situation. When the data in the current study are considered in light of previous work (e.g., Abernethy & Russell, 1981, 1984; Penrose & Roach, 1995; Renshaw & Fairweather, 2000 and Renshaw et al, 2003), the suggestion is that a more functional practice strategy may be to avoid prolonged use of the ball machine early in learning in order to educate learners' attention to the information-specifying sources available from the actions of real bowlers.

These arguments do not imply that projectile machines have no role in practice and learning of interceptive actions. However, prior to providing guidelines on when coaches should use bowling machines, an important question that needs answering is the impact of skill level on movement organisation when facing bowling machines. As Beek et al. (2003a) argued, the perceptual variables that need to be available to constrain movements of complete novices and advanced learners are different and specific to stages of learning. If skilled players are attuned to advanced information, then one should expect to observe relatively less change in movement organisation between the bowling machine and bowler conditions in unskilled players (who lack attunement to advance information) than in more skilled players.

Although this study extends our understanding of the area and provides some important findings, there is a need for more research that can enhance our understanding of the impact of common practice methods in sport. While we have demonstrated that the timing of movements against the bowling machine is different to that against real bowlers operating under net practice conditions, there is a need for empirical evidence to examine whether bowling machine practice is actually disadvantageous to batting against real bowlers under competitive conditions. Future work should examine the adaptability of timing and organisation of batsmen's movements under net practice conditions against real bowlers and bowling machines to examine their comparability to those observed under match conditions. Alternatively, a transfer design could be used to investigate to what extent is the performance of bowling machine-trained players against real bowlers a direct consequence of movement patterns acquired from over-specific and prolonged practice with the bowling machine.

In summary, we have provided evidence that changing the nature of informational constraints in a batting task leads to changes in timing and coordination of movement patterns. It seems more appropriate for learners to practice from an early stage under conditions where specifying information variables are available in the ecological constraints of the task. Given the focus on high-intermediate standard batsmen in our study, further research needs to manipulate ball speed and skill level in order to observe whether these factors impact on information-movement couplings. Additionally, an interesting practical issue would be to examine movement kinematics when batters are required to face bowlers with more unorthodox bowling actions.

References

Abernethy, B. (1981). Mechanisms of skill in cricket batting. *Australian Journal of Sports Medicine, 13*(1), 3-10.

Abernethy, B., & Russell, D. G. (1984). Advanced cue utilisation by skilled cricket batsmen. *The Australian Journal of Science and Medicine in Sport, 3*, 2-10.

Andrew, K. (1986). *Coaching cricket*. Ramsbury: The Crowood Press.

Araújo, D., Davids, K. & Serpa, S. (2005). An ecological approach to expertise effects in decision-making in a simulated sailing regatta. *Psychology of Sport and Exercise*, 6, 671-692.

Araújo, D., Davids, K. & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise*, 7, 653-676.

Araújo, D., Davids, K., & Passos, P. (2007). Ecological Validity, Representative Design and Correspondence between Experimental Task Constraints and Behavioral Settings. *Ecological Psychology*, 19, 69-78.

Bartlett, R. M. (2003). The science and medicine of cricket: an overview and update. *Journal of Sports Sciences, 21*, 733-752.

Beek, P. J., Dessing, J.C., Peper, C. E. & Bullock, D. (2003). Modelling the control of interceptive actions. *Philosophical Transactions of the Royal Society of London B,* 358, 1511-1523.

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. Ericcson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 321-344). Champaign: Human Kinetics.

Boycott, G. (1994). Preparing to bat and build an innings. In T. Lewis (Ed.), *MCC masterclass: The new MCC coaching book* (pp. 127-138). London: Weidenfield and Nicholson.

Davids, K., Renshaw, I. & Glazier, P. (2005). Movement models from sports reveal fundamental insights into coordination processes. *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 behavior in human movement systems. *Adaptive Behavior,* 14, 73-94.

Gibson, A. P., & Adams, R. D. (1989). Batting stroke timing with a bowler and a bowling machine: A case study. *The Australian Journal of Science and Medicine in Sport, 21*(2), 3-6.

Gibson, J. J. (1986). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Hubbard, A. W., & Seng, C. N. (1954). Visual movements of batters. *Research Quarterly, 25*, 42-57.

Jacobs, D. M., & Michaels, C. F. (2002). On the paradox of learning and realism. *Ecological Psychology, 14*(3), 127-140.

Land, M. F., & McLeod, P. (2000). From eye movements to actions: How batsmen hit the ball. *Nature Neuroscience, 3,* 1340-1345.

Montagne, G., Laurent, M., Durey, A., & Bootsma, R. (1999). Movement reversals in ball catching. Experimental Brain Research, *129*, 87-92.

Montagne, G. (2005). Prospective control in sport. *International Journal of Sport Psychology, 36*, 127-150.

Mullineaux, D., Bartlett, R., & Bennett, S. J. (2001). Research design and statistics in biomechanics and motor control. *Journal of Sports Sciences*, 19, 739-760.

Müller, S., Abernethy, B., & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *Quarterly Journal of Experimental Psychology*, 59, 2162-2186.

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.

Plagenhoef, S. (1971). *Patterns of human motion*. Englewood Cliffs: Prentice Hall.

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., Fairweather, M. M., Oldham, T. R. O., & Rotheram, M. (2003). *Do bowler's delivery characteristics influence spatial discrimination in batters?* Paper presented at the 2nd World Congress of Science and Medicine in Cricket, Cape Town, South Africa.

Savelsbergh, G. J. P., & Van Der Kamp, J. (2000). Information in learning to co-ordinate and control movements: is there a need for specificity of practice? *International Journal of Sport Psychology, 31*, 467-484.

Stretch, R. A., Buys, F., Dutoit, E., & Viljeon, G. (1998). Kinematics and kinetics of the drive off the front foot in cricket batting. *Journal of Sports Sciences, 16*, 711-720.

Tyldesley, D., & Whiting, H. T. A. (1975). Operational timing. *Journal of Human Movement Studies, 1*, 172-177.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport*. London: E and F. N. Spon.

Table 1: Mean joint segment angles (degrees) of the knee and elbow at key phases of the forward defensive shot in bowling machine and bowler conditions.(For effect size: small = <0.6, moderate = ES>0.6, large = ES>1.2, very large = ES>2).

		Ball Release	**Backswing Initiation**	**Front foot Initiation**	**Downswing Initiation**	**Front foot Placement**	**Impact**
Front Elbow	Bowler	137 ±4	131 ±6	130 ±4	114 ±6	112 ±11	124 ±15
	Machine	131 ±8 (ES=1.0)	129 ±10	122 ±6 (z= -1.96, p=0.05, 0.12<0.125, ES=1.6)	121 ±5 (z= -2.073, p=0.038, ES=-1.27)	126 ±10 (z= -2.416, p=0.016, ES=-1.33)	133 ±+7 (z= -1.891, p=0.059, ES=0.82)
Back Elbow	Bowler	135 ±5	128 ±9	122 ±7	84 ±8	93 ±10	123 ±15
	Machine	125±12 (z= -2.56, p=0.10, ES=-1.2)	124 ±13	103 ±8 (ES= 2.53)	93 ±8 (ES=-1.13)	112 ±13 (z= -2.784, p=0.005, ES=-1.65)	132 ±+9 (ES=-0.75)
Front Knee	Bowler	171 ±2	156 ±4	153 ±3	158 ±7	161 ±3	152 ±10
	Machine	169 ±2	167 ±4 (z= -2.558, p=0.011, ES=-2.75)	149 ±6 (ES= 0.89)	151 ±5 (z= -2.240, p=0.025, ES=-1.17).	159 ±4 (ES=0.57)	149 ±9 (ES=1.0)
Back Knee	Bowler	172 ±1	171 ±4	170 ±3	164 ±6	161 ±8	150 ±11
	Machine	170 ±2 (ES=1.33)	172 ±6	167 ±4 (ES= 0.86)	166 ±5	161 ±8	151 ±12

Figure Captions

Figure One: Differences in timing and coordination of the phases of the forward defensive shot for the bowler and bowling machine conditions from the point of ball release to ball-bat impact. (Figures are not to scale). The time “after” ball release is shown in parentheses.

Figure Two: Data for bat swing showing differences in the initiation points of the backswing and downswing in the bowler and bowling machine conditions.

Figure Three: Peak height of the backswing showing that batters (n=4) swing the bat back higher against the bowler.

Bowling Machine

Ball Release	Initiation of Backswing	Initiation of FFM	Initiation of Downswing	Front Foot Placement	Impact
0.66±0.06	0.64±0.10 (0.02)	0.50±0.04 (0.16)	0.34±0.04 (0.32)	0.13±0.05 (0.53)	0
0.66±0.06	0.54±0.04 (0.12)	0.52±0.03 (0.14)	0.25±0.03 (0.41)	0.11±0.05 (0.55)	0

Bowler

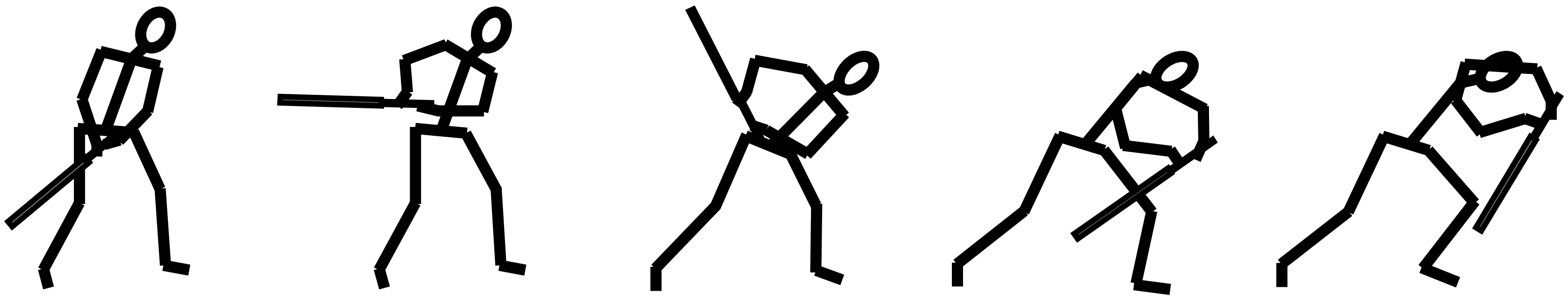

Figure One:

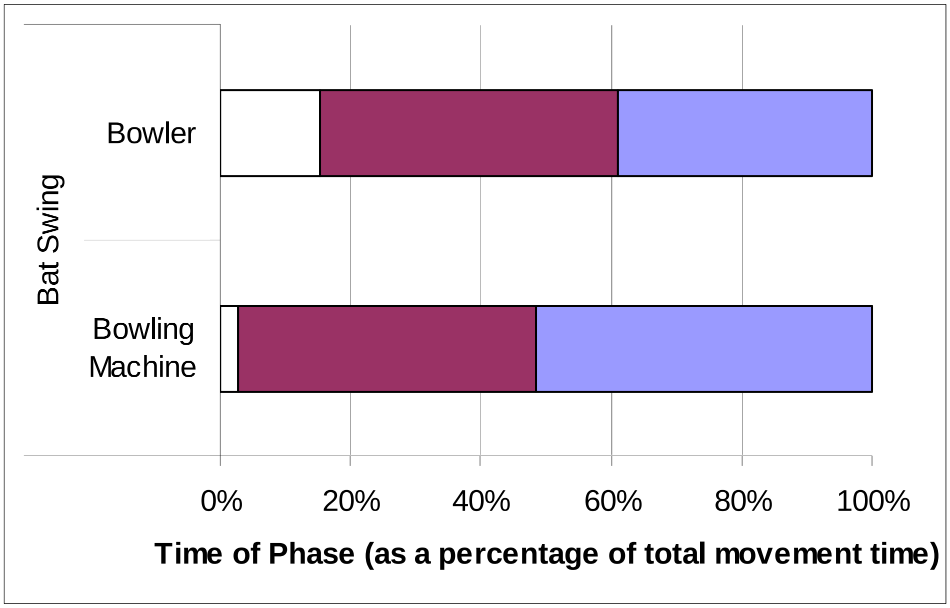
Bat Swing
Bowler
Bowling Machine
0%
20%
40%
60%
80%
100%
Time of Phase (as a percentage of total movement time)

Figure Two:

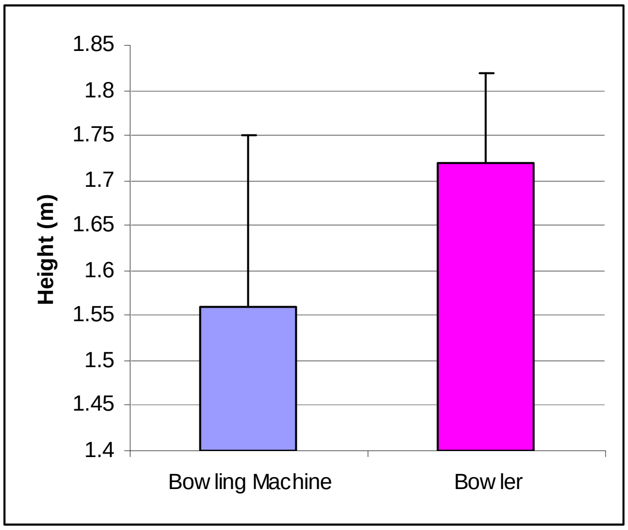

Figure Three:

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