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Implicit perceptual training: How, when, and why?

R.C. Jackson [a,*], D. Farrow [b]

[a] *Institute of Human Performance, The University of Hong Kong, 111–113 Pokfulam Road, Pokfulam, Hong Kong*

[b] *Australian Institute of Sport, PO Box 176, Belconnen, ACT 2616, Australia*

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Abstract

The perceptual skills underlying anticipatory movement in sport have been the focus of much research over the past 20 years. Methods for training such skills have tended to emphasise explicit specification of discriminative cues and the rules linking changes in the perceptual field with required responses. Recently, researchers have begun to examine less prescriptive methods of training. In the present paper, we examine conceptual, methodological, and practical issues associated with whether such skills can or indeed should be trained implicitly. The implications of two ways of conceptualising the explicit–implicit distinction for the methods used to promote implicit learning and the tests used to assess the nature of learning are considered. Finally, potential advantages of implicitly learned skills relating to task complexity and robustness under stress are discussed.

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* Corresponding author.
E-mail address: robjacks@hku.hk (R.C. Jackson).

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1. Introduction

Perceptual skills are central to the performance of many tasks in different domains, including everyday activities such as driving (Horswill, Waylen, & Tofield, 2004) and reaching and grasping (Goodale, Westwood, & Milner, 2003), as well as in the military (Endsley & Smith, 1996), medical (Sowden, Davies, & Roling, 2000) and sporting (Abernethy, 1987) domains. Perceptual learning refers to the relatively long-lasting change to an organism's perceptual system that improves its ability to respond to its environment (Goldstone, 1998). At a behavioural level, perceptual learning refers to improvements in complex perceptual-based skills as a result of training (Sowden et al., 2000). Explanations of perceptual learning have been sought from a cognitive perspective through mechanisms such as attentional weighting, stimulus imprinting, differentiation and unitization (Goldstone, 1998), and from an ecological perspective through emphasising the direct tuning of action to information embedded in the optic array (Gibson, 1979). Researchers have historically focussed upon a reasonably restricted range of topics with perceptual development in infancy, perceptual adaptation, picture perception and the development of cognitive maps being particularly prominent. While reviews of perceptual learning frequently cite examples of expert perceptual skills (e.g., see Goldstone, 1998), there has been relatively little direct theorising about, and experimental examination of, the perceptual skills supporting movement in "real-world" experts. This is surprising given that this domain may provide a unique perspective within which to examine fundamental issues in perceptual learning.

The focus of the current paper is on how the perceptual processes underlying skilled anticipation may be trained. We focus on the sporting domain; however, the issues we address are relevant to other domains, particularly those in which skilled performance is characterised by sensitivity to changes in a complex visual environment, such as driving and flying. Specifically, we focus on the explicit–implicit nature of anticipation training in an attempt to highlight conceptual, methodological, and practical issues surrounding proponents of less-directed training procedures. We begin by providing an overview of the expert advantage in sport tasks requiring rapid decision-making and then examine the methods that have been traditionally employed to train such skills. The potential benefits associated with less-directed approaches to training are then considered, first, by reviewing conceptual issues relating to the definition of implicit learning and, second, by outlining different procedures for minimising the contribution of explicit processes to learning. Finally, practical issues regarding possible advantages of less-directed approaches to training are discussed. Throughout, research on implicit perceptual training and discovery-learning techniques within the sporting domain are critically appraised in the context of the broader debate about implicit learning. Where appropriate, consideration is also given to the training of other perceptual-based skills and to research on implicit motor learning.

2. Perceptual expertise and traditional perceptual training

Expert performers in many sports demonstrate an ability to anticipate the actions of their opponent (Abernethy, 1987). Researchers have indicated that one of the underlying mechanisms of the expert advantage is the ability to use early visual information within the perceptual display. This ability has been demonstrated in many sports, including cricket (Abernethy & Russell, 1984), badminton (Abernethy, 1988, 1991; Abernethy & Russell, 1987), squash (Abernethy, 1990a, 1990b; Howarth, Walsh, Abernethy, & Snyder, 1984), karate (Mori, Ohtani, & Imanaka, 2002), tennis (Goulet, Bard, & Fleury, 1989; Jones & Miles, 1978; Rowe & McKenna, 2001; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996) and football (Williams, 2000; Williams & Davids, 1998). In addition, experts have been found to be better at assigning and making use of situational probabilities to guide anticipatory responses (Abernethy, Gill, Parks, & Packer, 2001; Paull & Glencross, 1997; Ward & Williams, 2003). Importantly, it is clear that skilled anticipation has a significant acquired component, reflecting a "software" as opposed to "hardware" advantage (Williams, Davids, & Williams, 1999). For example, the expert's advantage within his or her domain of expertise does not tend to transfer to tests of simple reaction time (e.g., Mori et al., 2002). In addition, while there is considerable evidence that measures of basic visual function can be improved with practice, this tends not to result in improved perceptual-motor performance. For example, Wood and Abernethy (1997) found that a four-week vision-training programme did not result in improvements in sport-specific perceptual measures or motor performance. Logically, these findings lead to the question of how best to train such skills.

Traditional perceptual training methods attempt to closely replicate or simulate the perceptual conditions present in the real-world competitive setting. In the sporting domain, the most examined method for training the perceptual skills underlying anticipation is postural cue identification, often accompanied by the use of temporally occluded video-based displays. This training technique requires players to learn the essential link between early cues (e.g., arm motion) and event outcome (e.g., serve direction). Interventions usually include a large explicit component in which performers are directed to attend to specific visual cues, coupled with repeated exposure to exemplar video stimuli, usually depicting a high-level performer. A representative example is the study by Abernethy, Wood, and Parks (1999) who conducted an intervention of 20 sessions over four weeks aimed at improving the ability of novice squash players to anticipate the direction and depth of forehand and backhand drive shots. The programme consisted of six components, including formal instruction about the biomechanical properties of the forehand and backhand drive shots, and formal instruction about the most important cues for anticipating shot depth and direction. The remaining components were designed to give the participant practice at focusing on these information sources and making appropriate verbal and physical responses.

The results of traditional perceptual training interventions tend to indicate improved decision speed and/or accuracy. For example, Abernethy et al. (1999) found that the perceptual training group significantly improved both shot direction and depth judgments relative to the placebo and control groups. Similarly, Singer et al. (1994) found that perceptual training resulted in faster movement initiation times in beginner/intermediate tennis players, using laboratory-based anticipation tests requiring performers to respond to visual footage displayed on a large screen. Other researchers have found that improved performance in either response time or accuracy sometimes occurs at the expense of poorer performance in the other. For example, Farrow, Chivers, Hardingham, and Sasche (1998) instructed novice tennis players to attend to the server's stance, ball toss, racquet position and speed. After eight, 15-min training sessions, in which players viewed temporally occluded video clips of advanced players hitting a variety of serve types and directions, the perceptual training group had significantly faster response times than either the placebo or control groups. However, this was offset by a decrease of approximately 22% in response accuracy. Similarly, Moreno, Oña, and Martínez (2002) trained recreational tennis players to respond to cues exhibited by professional players. Although only limited inferences can be made due to the absence of a control group, comparison both within and across performers again revealed a trade-off between response speed and accuracy.

In a review of perceptual training studies, Williams and Grant (1999) further noted that few studies had used placebo groups raising the possibility that benefits were due to test familiarity or Hawthorne effects. In addition, they highlighted the paucity of research examining transfer to the field setting and the equivocal findings from the few studies that had addressed this issue (e.g., Singer et al., 1994). Recent results regarding transfer to the field have been more encouraging (e.g., Farrow & Abernethy, 2002; Williams, Ward, & Chapman, 2003; Williams, Ward, Knowles, & Smeeton, 2002, but see also Jackson, 2003). For example, Williams et al. (2003) conducted a single 45-min training session that significantly decreased novice field-hockey goalkeepers' decision time when responding to video projections of penalty flicks. Furthermore, there was no cost in terms of accuracy and improvements in decision time transferred to "live" penalty flicks, again with no costs to accuracy. Using a multiple-baseline (across participants) design, Scott, Scott, and Howe (1998) also found improvements in on-court response accuracy in intermediate tennis players. In this case, the training intervention required players to predict serve type, depth, and landing position from video footage of serves occluded at ball–racquet contact. Initially, the video was played at 1/30 of normal speed, increasing once players reached a pre-determined criterion (75%). Following the intervention, all players improved their serve-return performance.

To summarise, traditional perceptual training studies have used interventions of varying duration (from a single 45-min session to sixteen 20-min sessions) that have tended to result in significant improvements in response accuracy and/or speed on laboratory-based tests. The precise methods have varied (e.g., use of slow motion) as has the degree of explicit information provided (from "tips" to formal biomechanical-based instruction) and the degree of transfer to the field setting has been variable.

From the perspective of the current paper, the unifying factor in traditional perceptual training interventions has been the attempt to make explicit the links between visual cues and response requirements.

3. Implicit learning

Reber's (1967) original conceptualisation of implicit learning highlighted similarities with perceptual differentiation (Gibson & Gibson, 1955), a process by which percepts become increasingly differentiated from each other after repeated exposure to variants of the stimuli. In particular, Reber (1967) characterised implicit learning as "a rudimentary inductive process which is intrinsic in such phenomena as language learning and pattern perception" (p. 863). Subsequently, several additional definitions were proposed, with one of the most common referring to implicit learning as the acquisition of information without necessarily intending to do so, and in such a way that the resulting knowledge is difficult to express (Berry & Dienes, 1993; Cleeremans, Destrebecqz, & Boyer, 1998). Frensch (1998) similarly defined implicit learning as the "nonintentional, automatic acquisition of knowledge about structural relations between objects or events" (p. 76). At the same time, he highlighted a lack of agreement over what constitutes implicit learning by citing 11 different definitions which varied in the extent to which they emphasised absence of awareness of the acquisition period, of the resultant knowledge, or of the retrieval of that knowledge. Detailed discussions about the most appropriate way to conceptualise implicit learning exist elsewhere in the literature (Dienes & Berry, 1997; Reber, 1997; Shanks & St. John, 1994; Stadler, 1997; Sun, Slusarz, & Terry, 2005) and are beyond the scope of the current paper. Instead, we focus on the two ways in which implicit learning has been broadly conceptualised and the implications of each of these for the training of anticipation skill. Specifically, we contrast the implications of viewing the explicit–implicit distinction in dichotomous terms with that of viewing it as a continuum.

Using the classic dissociation procedure, pure implicit learning is demonstrated when an improvement on the task of interest occurs in the absence of explicit knowledge about how to perform the task. In a critique of the evidence for dissociable learning systems, Shanks and St. John (1994) argued that researchers had failed to provide convincing evidence for implicit learning. A significant part of their paper focused on the methods used to assess explicit knowledge. First, they made the logical argument that tests of explicit knowledge must assess the information that is actually responsible for performance changes (the information criterion). This highlighted the problem of participants applying explicit rules that were not considered relevant (by the experimenter, the learner, or both) but were positively correlated with the underlying rules of the task. Second, Shanks and St. John (1994) argued that tests of explicit knowledge should be sufficiently sensitive to detect all relevant conscious knowledge acquired by participants (the sensitivity criterion). They argued that verbal reports were not sufficiently sensitive tests of explicit knowledge; for example, participants may not report information they hold with low confidence. More generally, Shanks and St. John (1994) suggested that making the retrieval context of the performance and awareness tests as similar as possible could enhance sensitivity when assessing awareness. Similar problems with demonstrating perception without awareness using the dissociation procedure were highlighted by Reingold and Merikle (1988). The central issue was how to demonstrate that measures employed to assess conscious perceptual experience were sufficiently sensitive to detect all relevant consciously perceived information.

An alternative procedure for establishing implicit learning, which may be particularly appropriate to anticipation training studies, is to adopt subjective criteria for establishing implicit learning. Dienes and Berry (1997) described two such criteria: the guessing criterion and the zero-correlation criterion. Originally described in the perception literature (Cheesman & Merikle, 1986), the guessing criterion states that participants have unconscious knowledge if they claim to be purely guessing but nevertheless perform above chance levels. The zero-correlation criterion concerns the relationship between confidence and improvement in performance: if the two are unrelated, this is considered evidence that implicit processes are contributing to learning (Dienes, 2004; but see also Buchner, Funke, & Berry, 1995). Many tasks used in perceptual training studies employ a forced-choice response paradigm that is clearly open to objective assessment of chance-level performance. By recording participants' confidence following each trial it should also be possible to establish, first, the trials on which they believe they are purely guessing, and, second, the relationship between performance and confidence. Additional evidence for implicit learning might be demonstrated by improved performance in the absence of increased confidence. For example, in a study of anticipation training, Poulter, Jackson, Wann, and Berry (this issue) used confidence ratings alongside free-recall and forced-choice tests of awareness. Interestingly, although the free-recall and forced-choice tests revealed differences between explicit and implicit learning conditions, confidence in decisions did not increase in either group. These data can be interpreted as evidence for both explicit and implicit processes contributing to improvement in the early stages of learning. That is, participants may be aware of the cues at which they are looking and the rules linking changes in features of the visual stimuli to response requirements but still be unaware (hence not confident) of the underlying process of differentiation that improves performance.

As it may be methodologically difficult to create pure implicit learning conditions (Seger, 1997), an alternative is to attempt to determine the relative contribution of implicit and explicit processes to a learning episode. This requires viewing the relationship between explicit and implicit learning as a continuum along which their relative contribution can vary (Reber, 1997) and, second, the use of valid measures of the contributions of explicit and implicit processes. Experiments undertaken in the motor and/or sporting domains have favoured using self-report tests of explicit knowledge as manipulation checks for implicit learning interventions (e.g., Masters, 1992), while relative rule-use has formed the basis of distinctions between explicit and learning in the perceptual training literature (Farrow & Abernethy, 2002; Raab, 2003). Issues surrounding relative rule-use as an indicator of explicit learning are considered in the following section as we consider methods for promoting implicit perceptual training in the sporting domain.

4. How can implicit perceptual training be conducted?

For many perceptual and perceptual-motor skills, learning may be considered to be largely implicit because the role of explicit knowledge (and hence explicit instruction) during learning is limited. For example, Beek (2000) argued that acquiring many perceptual-motor skills draws heavily upon functional levels of organisation that are cognitively inaccessible, to the extent that explicit learning is the exception rather than the rule in the perceptual-motor domain. Similarly, as already noted, Reber (1967) characterised implicit learning as similar to perceptual differentiation, thought to be a relatively primitive process of adaptation to the sources of variation present in the environment. However, explicit instruction is the rule rather than the exception in visual discrimination tasks that are the focus of perceptual training interventions. This is apparent in the training of perceptual-based anticipation and other complex perceptual-discrimination skills. For example, Sowden et al. (2000) noted that current approaches to teaching identification of abnormalities in medical X-ray images usually emphasise the development of conceptual knowledge via explicit, class-based instruction. Consequently, whether the explicit–implicit distinction is viewed in dichotomous or relative terms, the challenge is to create an environment in which explicit learning, conscious hypothesis testing, and awareness of what is being learned are either minimised or systematically manipulated. The three methods that have been used in implicit perceptual training or motor learning literature are now critically evaluated in relation to the different conceptualisations of implicit learning. In Table 1, we also summarise the range of approaches that have been used to train anticipation skill in sport, from highly directed, explicit training to less-directed discovery learning, to approaches that attempt to prevent explicit learning altogether.

4.1. Withholding explicit instruction and (guided) discovery learning

Clearly, if participants are to learn a task without formulating rules then task-relevant explicit instruction must be withheld. This is, then, a necessary condition for implicit learning; however, evidence suggests it does not significantly suppress explicit processing because participants are not prevented from formulating their own rules or testing their own hypotheses while interacting with the task (Masters, 2000). This has been clearly demonstrated in instrumental learning tasks distinguishing between verbal-governed behaviour and behaviour that is shaped by consequences of responding. Shimoff, Matthews, and Catania (1986) used the term *pseudosensitivity* to describe performance that appeared to have been shaped but was in fact largely under the control of verbal hypotheses (see also Rosenfarb, Newland, Brannon, & Howey, 1992). Furthermore, the experimental set-up in most discovery learning experiments is such that participants intend to learn, which has been shown to invoke significant explicit processing and hypothesis testing (Dienes & Berry, 1997). Indeed, in a golf putting experiment, Maxwell, Masters, and Eves (2003) found that hypothesis testing still occurred when visual feedback about the outcome of each putt was eliminated.

Table 1
A summary of different approaches used in perceptual training studies in sport

Type of training	Characteristics
Explicit instruction	Instructions vary in number and level of precision but aim to explicate a causal relationship between particular cues and/or patterns of movement and a relevant behavioural outcome (e.g., a tennis serve directed to the left or right). Typically a large number of rules are reported
Guided discovery	Less directed than explicit instruction, performers are guided to general regions (e.g., the midriff) and are left to discover the relationships between cues/movement patterns and behavioural outcomes. Typically fewer rules are reported than in explicit learning
Discovery learning	Less directed than guided discovery, explicit instruction is withheld. Typically fewer rules are reported than in guided discovery learning
"Implicit learning" via use of concurrent secondary tasks	Concurrent secondary tasks used to suppress involvement of working memory and, by implication, explicit processes. Limited use in perceptual training to date but motor learning literature suggests that suppression of explicit learning and performance on the primary task vary according to the nature of the secondary task that is used
"Implicit learning" via incidental learning	Performer is distracted from the primary learning task by a cover story, typically implying a memory task. Limited evidence thus far suggests performers still report several rules relating to the primary task
"Implicit learning" via distraction tasks	An explicit contingency is stated in which the performer aims to learn a different aspect of the skill (e.g., tennis serve speed as opposed to direction). Sensitivity to the implicit contingency is then measured. Rules likely to be generated about the distracter task, creating possibility of correlated hypotheses

The difficulty associated with determining the explicit–implicit nature of discovery learning is apparent in Williams et al.'s (2002) comparison of guided discovery and explicit approaches to training anticipatory movement in recreational tennis players. Overall, the results were supportive of discovery learning: the experimental groups made equivalent improvements in decision time and response accuracy that were significantly greater than in the placebo and control groups. But although learning in the guided discovery group was later described as conveying similar benefits to those demonstrated via implicit learning, procedural details reveal that they were instructed to focus their attention on general body regions (e.g., the midriff) in the hope of discovering through trial-and-error learning the relationships between important cues and shot outcome. Rule-discovery protocols have previously been used to elicit an explicit mode of learning (Turner & Fischler, 1993), so it would seem likely that participants may have tested hypotheses and still accumulated a significant number of rules. A subsequent study comparing explicit, discovery, and guided discovery conditions revealed this to be the case (Smeeton, Williams, Hodges, & Ward, 2005). Participants in the guided discovery group reported using a mean of 4.9 rules. While this was significantly lower than the number of rules reported by participants in the explicit training group (9.5), it was higher than that reported by the discovery learning group (2.0).

If conceptualising the explicit–implicit distinction in dichotomous terms, discovery learning in these experiments is clearly not implicit. Even using self-report measures that may lack sensitivity (Shanks & St. John, 1994), participants typically report using *some* rules when learning via discovery. If conceptualising the distinction in relative terms, there are issues about where to establish the cut-point (Reber, 1997) and, second, whether the number of free-report rules is a valid measure of the contribution of explicit processes to the learning episode. These issues aside, Reber admits a "lingering affection for free introspective report" (p. 50) and relative rule-use may be a particularly appropriate measure in cases where the degree of rule-use is likely to vary considerably, as is the case when comparing explicit learning with a range of less-directed instructional conditions. Although certain instances may be problematic (e.g., the case where a participant consistently applies the same, single, explicit rule throughout the learning episode), the utility of the measure will ultimately be determined by its ability to identify behaviour that changes in line with a theory about the nature of that behaviour (Dienes, 2004). For example, if the number of self-reported task-relevant rules is predictive of performance failure under stress, and if the inability to report such rules is predictive of robustness under stress, then the measure will be useful in helping to design learning protocols and to identify existing protocols that have this characteristic. It may also help researchers to identify the common underlying mechanisms associated with different interventions (cf. Williams et al., 2002).

4.2. Manipulating attentional resources

Reflecting a functional approach to implicit learning, the rationale for manipulating attentional resources is that the explicit, conscious, hypothesis-testing system requires attention (Cleeremans et al., 1998). Assuming implicit processes operate relatively automatically and independent of the explicit system, learning should be largely implicit under dual-task conditions because learners have limited resources available for testing hypotheses and formulating rules about the primary task. Early research using different learning tasks was largely supportive of this prediction. For example, using the dynamic systems paradigm, Hayes and Broadbent (1988) found that concurrent random letter generation disrupted primary task performance when the relationship between input and output was salient. When it was made less salient, by introducing a lag between input and output, task performance was unaffected by addition of a secondary task. Similarly, Svartdal (1992) found that the emergence of sensitivity to contingencies of which participants were unaware was unaffected by increasing primary task difficulty. Other research indicated that learning is retained, although at a somewhat suppressed level under dual-task conditions (Nissen & Bullemer, 1987; Sun, Merrill, & Peterson, 2001).

Concurrent secondary tasks have been used to promote implicit motor learning and have proved effective at significantly reducing the number of rules accumulated in laboratory settings (Masters, 1992; Maxwell, Masters, & Eves, 2000; Maxwell et al., 2003). A limitation, at least in the motor learning literature, is that it has proved difficult to find tasks that successfully suppress explicit knowledge while leaving performance on the primary task unaffected (McMahon & Masters, 2002). In addition, the attentional demands associated with secondary tasks tend to decrease over time (Nissen & Bullemer, 1987), which may compromise their practical utility as a means of promoting implicit learning over extended periods. Their practical utility is further limited because they do not suppress explicit learning in periods when the secondary tasks are not being performed. Finally, care must be taken to avoid structural interference between the primary and secondary tasks. Recent use of tone-frequency judgment (Gray, 2004), tone-frequency monitoring, and word-monitoring tasks (Beilock, Carr, MacMahon, & Starkes, 2002) in baseball, golf putting, and soccer skills appear promising in this regard.

Overall, the manipulation of attentional resources offers a well-established means of suppressing hypothesis testing and, by implication, increasing the contribution of implicit processes to learning. Concurrent secondary tasks also offer a means of promoting implicit learning in the field setting, where it may be difficult or impossible to suppress the intention to learn, and where performers may have already acquired some task-relevant knowledge. However, their practical utility in this setting may be restricted to relatively brief learning episodes of the sort typically encountered in experimental research in this area, and to the short-term suppression of explicit knowledge in more skilled performers (Beilock et al., 2002). An alternative to using secondary tasks is to structure training in such a way that performers feel less inclined to generate hypotheses about the primary task of interest.

4.3. Distraction tasks and incidental learning

A third method for minimising explicit learning is to create an incidental learning condition by directing the participant's attention away from the primary learning task. The memory task employed by Reber (1967) in his early research on artificial grammar learning may be characterised in this manner and this technique was recently used to promote implicit learning of decision-making in sport (Raab, 2003). A limitation of this approach is that participants often remain able to report some knowledge about the stimuli presented (Perruchet & Pacteau, 1990; Shanks & St. John, 1994). For example, Raab (2003, Experiment 1) found that knowledge ratings of the group asked to memorise patterns of play were not significantly different from the explicit group in the simple-decision task.

A second means of distracting participants from the primary task is to have them believe that their performance is dependent on one feature of responding when, in fact, it is determined by another. For example, Svartdal (1992) led participants to believe that their success (the explicit contingency) was contingent upon accurately tapping out the number of tones they heard through headphones when it was in fact contingent upon the force of their movements when pressing the button (the implicit contingency). Svartdal (1992) found that, when responding, participants became sensitive to the implicit contingency even though post-experiment reports indicated they were unaware of this contingency. A variant of this technique was recently applied in Farrow and Abernethy's (2002) study of implicit perceptual training in tennis.

Participants were led to believe their task was to judge the speed of each serve when it actually focussed on the ability to predict serve direction. It was reasoned that, by attending to serve speed, players would implicitly establish relationships between serve kinematics and resultant serve direction.

There are at least two potential advantages associated with distraction-based strategies: First, by engaging participants with a different task or feature of the task, it seems unlikely that participants will actively test hypotheses for the task of interest. Second, the distractor task may demand attentional resources, further limiting the participant's capacity for testing hypotheses and formulating rules about the primary task. It may also be speculated that having the participant actively engage with a distractor task is more motivating than having them perform a concurrent secondary task such as backward counting. Shanks and St. John (1994) have argued that tests of explicit knowledge would likely violate the information criterion in this instance. Specifically, a potential problem is that rules generated by participants for the explicit contingency may correlate with rules governing the implicit contingency. For example, Farrow and Abernethy (2002) tried to prevent participants in the implicit learning group from formulating rules about serve direction by instructing them to make judgments about serve speed. When subsequently asked how they determined serve direction, they reported an average of less than one rule. Applying the information criterion, it cannot be assumed that this group learned implicitly because rules generated for determining serve speed may also help discriminate serve direction. For example, serves down the centre tend to be faster than those out wide; therefore, a "fast serve" rule may also indicate "serve down the middle". Nevertheless, to the extent it can be demonstrated that knowledge acquired for the distractor task does not facilitate learning of the primary task, distraction-based strategies offer a potential means of promoting implicit learning. They may be particularly useful if distractor tasks can be chosen that direct participants' visual gaze to appropriate regions of the display while suppressing hypothesis-testing for the response parameter of interest.

5. When and why should implicit perceptual training be used?

From an applied perspective, the pertinent question for practitioners training anticipation skill is why they should employ methods to promote a more implicit mode of learning. To this end, advantages over traditional, more explicit training methods need to be demonstrated. In the final section, two possible advantages of implicit training that appear particularly relevant to skilled anticipation are considered. The first concerns evidence that task complexity moderates the effectiveness of implicit learning. The second concerns evidence that implicitly learned skills are more robust under stress.

5.1. Task complexity

A number of studies using the artificial grammar learning (Dienes, Broadbent, & Berry, 1991; Reber, 1976), dynamic systems (Berry & Broadbent, 1984; Lee, 1995), and sequential learning (Howard & Howard, 2001) paradigms have indicated that the benefits of explicit instructions are moderated by task complexity. In particular, instructions to search for the underlying rules have been shown to improve performance in novices when such rules are salient or simple but either have no effect or impede performance when they are complex. For example, Lee varied the complexity of rules linking the input and output of two numbers. In the simple task, the two output values resulted from single simple equations (e.g., Output $1 = 0.5 \times$ Input 2) whereas in the complex task the output values were the result of double calculations based on both input values (e.g., Output $1 = [3.5 \times$ Input $1] + [4 \times$ Input 2]). Instructing novice participants to search for the underlying rules facilitated performance on the simple task but either had no effect or was detrimental to performance on the complex task. By contrast, Gomez (1997) presented evidence, using a sequential grammar-learning paradigm, that less complex information could be learned implicitly whereas learning of more complex relationships between stimuli was linked to explicit knowledge. Gomez defined complexity in terms of the specific as opposed to abstract nature of the underlying structure, varying from first-order serial dependencies (event y depends on prior event x) and specific surface knowledge to higher-order dependencies (event z depends on a least two prior events) and abstract knowledge. Serial dependency of the sort described by Gomez (1997) is an additional mechanism that may underlie skilled anticipation and warrants further investigation in both sport and other domains.

Thus far, only one study has examined the moderating effect of task complexity on different instructional conditions in the anticipation training literature. Raab (2003) defined complexity according to the number of "If–Then" rules available and the detectable difference between perceptual stimuli that form the basis for decisions. Focusing mainly on the complexity of "If–Then" relationships and varying the complexity of the relationship between each input and output, Raab compared explicit and implicit learning of decision making in several team sports. In the first experiment, a simple basketball decision-making task was used in which participants were required to make judgments on a "centre-rotation" play. Four "If–Then" rules, each specifying a unique combination of situation and required response (e.g., "If the defence player is far away then shoot to the basket") were given to the explicit learning group. Participants in the implicit learning group were given no instructions and were informed that they were taking part in a memory experiment. Specifically, they were asked to memorize five out of 10 decisions taken by the target player in the video clips. After a four-week training period, the implicitly trained group made more correct decisions than the explicit learning group. By contrast, when a more complex handball task was used (a "3 vs. 3 attack against a 3:2:1 defence system") in which five "If" conditions mapped on to 15 "Then" actions, the explicit group were more accurate than the implicit group. These results were largely replicated in two additional studies using simple handball and complex volleyball tasks.

These findings are consistent with those of Gomez (1997); however, there was evidence that response accuracy was at least partly confounded by response speed. For example, in the simple basketball task, the implicit learning group took approximately 0.65 s longer to make their (more accurate) decisions than the explicit learning group.

Similarly, in the complex handball task explicit learners were approximately 0.45 s slower in making their (more accurate) decisions than the implicit learning group. Both speed and accuracy are defining features of skilled anticipation, therefore, caution should be expressed when considering one parameter in isolation from the other.

Raab (2003) also defined complexity in terms of the detectable difference between stimuli. This perceptual component of anticipation is closely related to the mechanism of stimulus differentiation, which has been highlighted in several different domains of expertise, including wine tasting, medical diagnosis from X-rays, and the sexing of day-old chicks (Goldstone, 1998; Sowden et al., 2000). For example, experts have been found to be able to distinguish between male and female day-old chicks even though secondary sexual characteristics do not become apparent to the untrained eye until approximately one month after hatching. They can do this extremely quickly and accurately, sexing up to 1400 chicks per hour with an accuracy of up to 99.5% (Dreyfus & Dreyfus, 1986).

In terms of the explicit–implicit nature of learning, it is interesting to note that simple exposure, even without feedback, has been found to be sufficient for differentiating visual stimuli. For example, the ability to make fine resolution discriminations has been demonstrated on vernier tasks after less than one hour of training (Fahle, Edelman, & Poggio, 1995) while early, rapid improvements in the ability to detect features in X-ray like images have been found to be a function of the amount of exposure to the relevant features (Sowden et al., 2000). The benefits of explicit instruction also appear to be limited in such skills. For example, 95% accuracy in the skill of chick-sexing is reportedly acquired over a 1.5–3.5 month period of sexing live birds that were then checked by an expert (Biederman & Shiffrar, 1987). Biederman and Shiffrar (1987) found that novices were able to apply simple, explicit rules when classifying photographs depicting "rare and difficult types", achieving 84% accuracy after a training period lasting only a few minutes. While this was interpreted as evidence of the effectiveness of explicit instructions, the exceptional nature of the stimuli may have aided verbal classification of those instances in novices that would have been more difficult had more typical photos been used. For example, rare or exceptional stimuli have been found to elicit instance-based as opposed to rule-based classification in experts in concept learning experiments (Regehr & Brooks, 1993).

If one accepts that differentiation is relatively free of explicit processes (Reber, 1967), this literature suggests that the function of explicit instruction in enhancing anticipation skill may primarily be one of directing performers' attention to the information-rich regions of the display (Magill, 1998). In the complex visual arrays that are typical of many sport scenes, such instructions should prove beneficial and highlight the potential role of interventions aimed at changing visual search patterns of performers. For example, differences have been found in both the temporal and spatial aspects of visual search patterns between elite and lower-level performers (Ripoll, Kerlirzin, Stein, & Reine, 1995; Williams & Davids, 1998, but see also Abernethy, 1990b) and, recently, between elite and near-elite performers (Martell & Vickers, 2004). The scope for training visual search to enhance anticipation skill clearly warrants systematic investigation both with respect to the issue of complexity and the potential importance of serial dependency in skilled anticipatory movement.

5.2. Performance under stress

Implicitly learned motor skills have been found to be more robust under stress than skills learned either explicitly or by simply withholding instruction (Masters, 1992; Hardy, Mullen, & Jones, 1996). Although not attempting to induce implicit learning conditions, Smeeton et al. (2005) recently compared the robustness of explicit, discovery and guided discovery learning techniques in young intermediate tennis players. They found that the explicitly trained group slowed significantly more than either the discovery or guided discovery group in the anxiety condition. The explicit group also became less accurate, suggesting the results were not due to speed-accuracy trade-off. Furthermore, the increase in decision time in the explicit players was positively related to the number of rules accumulated during the learning period ($r = .76$). Comparison of changes in response accuracy for each group in the anxiety condition coupled with the number of self-reported rules lends further credence to the possibility that the extent of explicit knowledge mediates this process. The discovery-learning group generated fewest rules (2.0) and had the smallest decrement in response accuracy (−9%) that was offset by faster decision times (−99 ms). The guided-discovery group generated more rules (4.9), had a larger decrement in accuracy (−12%) again offset by slightly faster decision time (−71 ms). The explicit group generated the most rules (9.5), suffered the largest decrease in response accuracy (−17%) that was accompanied by an increase in decision time (+334 ms).

These findings are consistent with a growing body of research implicating explicit monitoring in skill failure under stress (Beilock & Carr, 2001; Gray, 2004; Masters, 1992). In particular, the relationship between rule-use and performance failure, although based on a small sample size, hints at the possibility that implicitly learned anticipation skills could prove more robust under such conditions. Indirect support for this possibility includes evidence that concurrent secondary tasks have a less detrimental effect on the anticipatory performance of experts than novices (Rowe & McKenna, 2001), suggesting that skilled anticipation, like skilled motor behaviour, is a relatively effortless, automatic process.

6. Conclusion

With the advent of digital cameras and increasingly powerful computers, it has become easier to manipulate the form and manner in which visual information is presented. In the sporting domain, this has increased the range of possibilities for video-based training yet the procedures used to train perceptual skills underlying anticipation have, almost exclusively, promoted a highly explicit form of learning. These have proved somewhat effective in improving decision-making speed and/or accuracy on video-based decision tasks but questions remain regarding their effectiveness, particularly in terms of transfer to the field setting.

Magill (1998) argued that regulatory features of the environment should be learned implicitly, so that the learner can use such features but remains unaware of the specific characteristics determining performance. In the present paper, we have highlighted some of the conceptual, methodological and practical issues associated with this proposal. Some of these appear particularly challenging for complex skills such as anticipation, which are usually subject to intentional learning over a considerable period of time (Ericsson & Lehmann, 1996). Specifically, how practical is it to implement implicit learning protocols when expert performance in both sport and other domains is the result of extensive deliberate practice and hypothesis testing over many years? At the same time, procedures developed for use in other implicit learning paradigms appear well suited for manipulating and measuring the contribution of explicit and implicit processes to learning. With increasing interest in how explicit and implicit processes interact during learning (e.g., Jiminéz & Méndez, 2001; Sun et al., 2005), and with training typically involving a combination of repeated exposure and explicit instruction, anticipation skill in sport may provide a fertile ground for studying such interactions.

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