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Perceptual Training Methods Compared: The Relative Efficacy of Different Approaches to Enhancing Sport-Specific Anticipation

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The comparative efficacy of different perceptual training approaches for the improvement of anticipation was examined using a goalkeeping task from European handball that required the rapid prediction of shot direction. Novice participants ($N = 60$) were assigned equally to four different training groups and two different control groups (a placebo group and a group who undertook no training). The training groups received either (i) explicit rules to guide anticipation; (ii) direction as to the location of the key anticipatory cues provided either just verbally (verbal cueing) or supplemented with color highlighting (color cueing); or (iii) undertook a matching judgment task to encourage implicit learning. Performance of the groups was compared on an anticipation test administered before training, after the training intervention, under a condition involving evaluative stress, and after a 5-month retention period. The explicit learning, verbal cueing, and implicit learning conditions provided the greatest sustained improvements in performance whereas the group given color cueing performed no better than the control groups. Only the implicit learning group showed performance superior to the control groups under the stress situation. The verbal cueing, color cueing, and implicit learning groups formulated the lowest number of explicit rules related to the critical shoulder cue although the reported use of general cues and rules based on all cues did not differ between any of the groups. Anticipation can be improved through a variety of different perceptual training approaches with the relative efficacy of the different approaches being contingent upon both the time scale and conditions under which learning is assessed.

Keywords: anticipation, perceptual learning, skilled performance, visual perception

The capability to make accurate predictive or anticipatory judgments is fundamental to successful task performance in many domains, especially those that involve inherently severe time constraints. It has been well established that expert performers in competitive ball sports, for example, have superior anticipation and pattern recall/recognition skills compared to less-skilled/less-successful performers (e.g., Starkes, 1987; Williams & Davids, 1995). The expert advantage in anticipation appears to be based around both the experts' sensitivity to sources of information to which the less-skilled are not attuned and their capability to pick up more information from the same cues to which the nonexperts attend (e.g., Abernethy & Russell, 1987a; Müller, Abernethy, & Farrow, 2006).

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The information to which experts are selectively sensitive appears to be contained largely within the kinematics of their opponent's movements, with similar expert–nonexpert differences being apparent in point-light (biological motion) displays as in normal displays (e.g., Abernethy, Gill, Parks, & Packer, 2001; Abernethy, Zawi, & Jackson, 2008). The superior pick-up of this information by experts is sometimes but not necessarily associated with differences in visual search/gaze behavior (cf. Abernethy & Russell, 1987b; Martell & Vickers, 2004; Williams, Ward, Knowles, & Smeeton, 2002). Given the importance of well developed anticipation skills to expert performance, and given the growing knowledge about the mechanisms underpinning the expert advantage, there is substantial interest from both theoreticians and practitioners alike in finding training methods to accelerate the acquisition of these skills, effectively making less-skilled performers more expert-like more quickly.

The study of perceptual training in the sports domain has quite a long history (for reviews see Abernethy, Wann, & Parks, 1998; Ward et al., 2008; Williams & Grant, 1999; and Williams & Ward, 2003). Early studies (e.g., Damron, 1955; Haskins, 1965) were principally concerned with the determination of whether watching either tachistoscopic or film displays could enhance recognition and response time in sports such as American football and tennis. Studies that followed that were informed by evidence on the nature of the expert advantage in these sports (e.g., Farrow, Chivers, Hardingham, & Sachse, 1998; Singer et al., 1994) sought to provide training that highlighted the key task cues (and those used by experts) in a very prescriptive and explicit manner.

Abernethy, Wood, and Parks (1999) provided learner squash players with 20 training sessions over 4 weeks in which formal instruction was provided about the mechanics of the strokes to be anticipated and the location of the critical cues used by experts. Repeat exposures were also given to temporally occluded images of opponents executing squash strokes. The display used in training was one that simulated the normal on-court viewing perspective of the player. The group given this intervention showed significant pre- to posttraining improvement in anticipatory skill that were not evident in either a placebo group (who received the same amount of training time but spent it watching coaching videotapes and match replays) or a control group (who undertook no training). Studies of this type have typically revealed improvements for the group receiving perceptual training compared to controls, with improvements evident in laboratory tests of anticipation showing transfer to the field setting in some (e.g., Scott, Scott, & Howe, 1998; Williams, Ward, & Chapman, 2003) but not all circumstances (cf. Farrow et al., 1998; Singer et al., 1994).

The approach of using formal instruction to enhance the learning of key perceptual skills was grounded in Anderson's (1982, 1993) theory of cognitive skill acquisition and the putative benefit of explicit instruction and conscious learner engagement to declarative knowledge development. For the past decade or more, however, there has been a growing awareness of the potential limitations in the use of explicit instruction and the type of perceptual learning that it may promote (Jackson & Farrow, 2005). Studies in the motor domain (e.g., Masters, 1992, 2000) indicate that skills acquired implicitly (i.e., without the accumulation of concurrent knowledge that can be verbalized; Maxwell, Masters, & Eves, 2000) may be more resistant to forgetting and more robust under the presence of stress than skills acquired explicitly (for a review see Masters & Maxwell, 2004). Explicit monitoring of the execution of a skill appears to predispose the skill to failure under stress (Beilock & Carr, 2001; Gray, 2004).

To date, there have only been a handful of studies that have attempted to develop (more) implicit approaches to the learning of anticipation skills and contrast their efficacy with those of more traditional, explicit forms of instruction and training. These (more) implicit approaches have involved methods in which either (i) implicit learning is encouraged through the use of concurrent tasks, incidental learning or distracting tasks designed to prevent learners undertaking hypothesis testing or (ii) guided discovery is used with instructions given to direct the attention of learners to those specific regions of the display that contain the critical information but without the provision of any explicit rules to help interpret and use this information (Jackson & Farrow, 2005). Magill (1998) has argued, in support of the guided discovery approach, that directing attention to those areas of the display that are most informative but without providing specific direction on what cues to use will likely provide the best balance between promoting implicit knowledge acquisition and minimizing time spent in an unproductive search for task information.

Farrow and Abernethy (2002) attempted to encourage implicit learning of anticipatory skills by having participants view videotapes of the service action of tennis players and make judgments about the speed of the serve they were observing. While completion of the speed prediction task required attention to be directed to kinematics of the service action, the goal of the task was clearly different to that of the criterion task of anticipating stroke direction and, therefore, did not encourage the development of explicit rules regarding the link between the observed kinematics and subsequent service direction. Players trained in this way showed a pre- to posttraining improvement on the criterion task that was not apparent either for players in an explicit group trained through direct instruction on the cues for anticipation of service direction or players in placebo and control groups. The players in the implicit training group verbalized less rules about how to predict service direction than did those in the explicit training group, suggesting that the training method had been successful in suppressing explicit learning while still promoting effective development of anticipatory skill. While the implicit learning approach appeared promising in providing perceptual transfer in the key time window known to differentiate experts from novices on this anticipation task (but see also Jackson, 2003), the improvement was small and short-lived, being no longer evident at a retention test performed 1 month later.

Smeeton, Williams, Hodges and Ward (2005) compared the performance of an explicit learning group (who were given detailed instructions of what cues to look for to identify shot direction), a guided discovery group (who were informed where to look for important information but not provided with rules for differentiating the different shot types), a discovery group (who were given encouragement to try and discover how to predict stroke direction but were given no instruction as to where to locate the critical information) and a control group who simply completed pre- and posttraining tests of anticipation. The groups were compared not only from pre- to posttraining but also during the acquisition phase and during a task designed to elicit competitive stress. The purpose of the stress task, which involved evaluative pressure, was to assess the proposition that the performance of the groups who learned under more implicit conditions would be more resistant to failure under elevated cognitive anxiety than the group who learned the skill through explicit rule formation (cf. Masters, 1992; Masters & Maxwell, 2004).

Smeeton et al. (2005) found that pre- to posttraining improvements in decision time were greater for all three intervention groups than the control group, with the most rapid improvements during the acquisition phase being observed for the explicit and guided discovery groups. Consistent with the expectations, the explicit training group reported more rules about the task than the other groups and the stress condition induced a decrement in performance for the explicit training group that was not apparent for the guided discovery and discovery learning groups. Smeeton et al. concluded, on the basis of their findings, that guided discovery represents the best option for training anticipatory skill based on the dual characteristics of fast acquisition and stress resistance. The extent to which such training benefits are retained is unknown given the absence of a longer-term retention test.

One possible means of drawing the attention of learners—either explicitly or implicitly—to key cues is to use color highlighting (Osborne, Rudrud, & Zezoney, 1990). Hagemann, Strauss, and Cañal-Bruland (2006) used a transparent red patch to help orient the attention of badminton players of different skill levels to critical anticipatory cues available in the hitting action of opposing players. The patch moved progressively, as the hitting action evolved, from the trunk, to the playing side arm and then racquet in a manner that matched both the transfer of summated forces within the stroke (Gowitzke & Waddell, 1991) and the pattern of information pick-up used by expert players (cf. Abernethy & Russell, 1987a; Abernethy & Zawi, 2007). Compared to participants given no training, novices given perceptual training with the patch present performed better on a typical video-based test of anticipation both immediately following training and after a retention period. No comparable benefits were evident for national-level players, perhaps because they may have already acquired the preferred information search strategy being taught within the video training. Performance of the group given color cueing was essentially comparable to that of participants who saw the same training videos but without the color patch, although those who experienced color cueing exhibited superior improvement over the period from posttest to retention.

There are at least two plausible means by which color cueing might bring about improvements in anticipatory skill. First, the presence of color may draw the participants' attention explicitly to the location of the critical information for anticipation and this conscious awareness may help guide selective attention and prediction in a functional way. Alternatively, being instructed to attend to color in a moving display may effectively place the participant in a dual-task situation with the color-attending requirement (task) actively diverting attention away from the anticipatory task, allowing more implicit, task-appropriate, processes to "take over".

For both practitioners looking for evidence-based guidance on the relative effectiveness of different types of perceptual training for enhancing anticipatory skill and for theoreticians interested in the mechanisms through which efficacious perceptual training might operate, the existing research base is quite severely limited. There are very few studies of perceptual training that include adequate control groups, suitably lengthy training periods, and appropriate posttraining retention tests (Williams & Ward, 2003). There are even fewer that examine the explicit–implicit dimension of training and, in so doing, include measures of rule formation (to assess the accumulation of explicit knowledge) and appropriately validated stress-inducing conditions (to assess the robustness of learning under cognitive anxiety) (Jackson & Farrow, 2005). Those studies that meet at least the majority of these requirements suggest possible benefits for approaches involving incidental learning (Farrow & Abernethy, 2002), guided discovery (Smeeton et al., 2005), and color cueing approaches (Hagemann et al., 2006), but demonstration of these benefits needs replication under conditions in which there is collection of both suitable process measures to examine the mechanisms through which any efficacious approaches may be operating and suitable dependent measures to help quantify, with confidence, any performance improvements that may accrue.

A particular problem that exists in a number of the current studies is failure to adequately account for possible speed–accuracy trade-off effects in the criterion tasks used to measure anticipatory skill (see also Abernethy et al., 1999). In tasks that require participants to respond both as quickly and accurately as possible, there is the ever present possibility of speed and accuracy of responding being traded off differentially between groups or, within groups, between the pretraining, posttraining and retention administrations of the criterion test. To date, studies using such measures of anticipatory and decision-making skill (e.g., Farrow et al., 1998; Smeeton et al., 2005; Williams et al., 2002) have simply analyzed the decision time and response accuracy components of task performance independently and not examined the possible relationship between the two components.

The purpose of this study was to directly compare the effectiveness of each of the major approaches to perceptual learning that have been advocated in the literature. We sought to do so by incorporating into our experimental design appropriate retention and stress tests, by examining the relationship between our concurrent performance measures of speed and accuracy, and by including measures of verbalizable rule formation to estimate the degree to which each approach captured the putative characteristics of implicit learning.

The performance of six different groups was compared on an anticipation test from goalkeeping in the sport of handball with the test administered before training, after training, during a stress-inducing situation, and at a time 5 months after the completion of the training intervention. The training groups were given either explicit learning, guided discovery via verbal cueing, guided discovery via color cueing, a new implicit approach based on incidental learning (cf. Jackson & Farrow, 2005), or a placebo condition, while the sixth group (the control) group received no training. Goalkeeping in handball was selected as the task of interest because success in the task requires both fast and accurate anticipation of shot direction (Gutierrez-Davila, Rojas, Ortega, Campos, & Parraga, 2011), and the presence of expert–novice differences in both anticipatory performance and information pick-up from specific cues from the thrower's movement patterns is already well-established (Schorer & Baker, 2009; Schorer, Baker, Fath, & Jaitner, 2007).

We predicted that the explicit learning group, the two guided discovery groups (verbal cueing and color cueing), and the implicit learning group would all produce pre- to posttraining improvements that would exceed that of the placebo and control groups and that this advantage would be preserved through to the retention test, especially for the group learning implicitly. We further predicted (i) that the implicit learning group would formulate fewer explicit rules for predicting the thrower's shot direction than would the verbal cueing and color cueing groups who, in turn, would formulate fewer rules than the explicit learning group, and (ii) that those groups with least explicit rule formation would demonstrate the most robust performance on the stress test. In relation to the relative performance of the two discovery learning groups, evidence was sought for the group receiving color cueing in addition to verbal cueing performing best, but without additional verbal rule formation, as an indication of color providing a facilitatory benefit through exogenous orientation of visual attention (cf. Yantis, 1998).

Method

Participants

The participants in this experiment were 60 undergraduate students in a sports studies program, none of whom had any prior experience in team handball generally or goal-keeping specifically. Nonplaying novices were selected as participants as they were undertaking no other concurrent handball-related activities with the potential to confound the effects of the training interventions given within the study. The mean age of the participants was 23.5 years ($SD = 2.4$). Twenty-nine of the participants were female and 31 were male.

The participants were randomly allocated to one of six groups until each contained $n = 10$ participants. The groups were an explicit learning group, a verbal cueing group, a color cueing group, an implicit learning group, a placebo group, and a control group. Forty-four (44) of the original 60 participants were available to participate in a retention test conducted 5 months after the original training sessions. The study was conducted in accord with the ethical guidelines of the American Psychological Association.

Experimental Design

The experimental design was based around three consecutive days of intensive testing and training followed by retention testing on a fourth day some 5 months later. On Day 1, participants in each of the six groups initially completed a customized video-based test designed to assess the speed and accuracy with which handball goalkeepers can anticipate the direction of shots on goal made by opposing players (see next section for details). Following this pretest (involving 48 trial sequences), participants in the training groups (but not those in the control group) then completed a further 144 trials of practice (on Day 1) and 192 trials (on Day 2) with the instructional set accompanying the practice differing dependent upon group assignment. On Day 3 all participants (including those in the control group) first completed the Revised Competitive State Anxiety Inventory-2 (CSAI 2-R) (Cox, Martens, & Russell, 2003) to provide a baseline measure of anxiety levels and then repeated the anticipation test completed on Day 1. Following this, participants then completed a test with stress induction and the CSAI 2-R inventory for the second time. Finally on Day 3, the participants also completed a questionnaire designed to determine their explicit knowledge of any rules underpinning their attempts to anticipate shot direction. Five months later (Day 4), the majority of the participants returned to complete the anticipation task for a third time.

Test Procedures

General test and training film construction and presentation. Four female handball players of first division league standard (two left-handed and two right-handed) were videotaped throwing a handball from the penalty line into each of the different corners of the goal. The video camera (Panasonic DVC-15) was positioned at a height (of ~ 1.80 m) and in such a location as to capture visual images typical of those normally available to the goalkeeper. The players were instructed to throw as naturally as possible—as they would in a game situation with a goalkeeper in front of them—with a minimum of 20 shots being recorded at each of the four corners of the goal (left-high, left-low, right-high, and right-low). Two female goalkeepers from the first division German league then viewed the recorded video clips and selected from these the 10 clips for each thrower to each corner that appeared most authentic and were most representative of the in situ goalkeeping task. Of the selected clips, one was incorporated within the anticipation test administered pre- and posttraining, and seven of the remainder were used within the training intervention. Two clips were not used at all.

Both the video clips used in the criterion anticipation task and those used in training were presented to the participants via a notebook computer (Acer Travelmate 661LCi, Taiwan) with a 15.1" (38.4 cm) screen. The selected video clips were presented in random order, using Presentation 9.20 software (Neurobehavioral Systems), with each clip temporally occluded at one of three different points in the throwing event. Occlusion on each occasion occurred either one frame (40 ms) before the ball had left the thrower's hand (t1), at the frame of ball release (t2), or one frame after the release point (t3). The participants' task on each trial was to predict the shot direction as quickly and as accurately as possible. As in a number of previous studies, the instructional set that was used was one that required the participants to attempt to optimize both response speed and accuracy and consequently created the possibility for a trade-off between these two response components. The response was made by pressing the most appropriate of four possible keys (*a*, *y*, *k* or *m* on a QWERTZ keyboard) that were selected so as to be maximally compatible with the predicted shot direction. The intertrial interval was 1 s.

Pretraining test. The pretraining test of anticipation skill was composed of 48 video trials—12 throws (to four different corners presented under three different levels of temporal occlusion) for each of the four different attacking players. The trials were presented in random order and in the absence of any trial-by-trial or summative feedback on performance. Completion of the test took, on average, some 10 min.

Posttraining test. The posttraining test was identical to the pretraining test in all ways except that a different random order of presentation of the 48 trials was used.

Stress test. Following the completion of the posttraining test, a test scenario was introduced that was designed to induce cognitive anxiety through evaluative pressure. The approach taken was based on that used by Gray (2004, Exp. 3). Participants completed a further anticipation test that again contained the same 48 trials as used in the pre- and posttraining test but again with a different randomized order of presentation of the trials. On this occasion, each participant was informed that they had been paired with another participant and, as an inducement to better performance, a 10 Euro reward would be provided to both members of the pair if both of them showed a 10% improvement in response time and response accuracy compared to the posttraining test. Each participant was then further informed that their assigned partner had already undertaken the second test and had achieved the 10% threshold. Aside from this, the instructions for completing the anticipation test were as in the earlier administrations of the test and again no performance feedback was provided during the course of the test. At the completion of the anticipation test (and the CSAI-2 R inventory), the participants were then fully debriefed as to the purpose of the stress induction scenario and were provided with the 10 Euro payment regardless of their actual performance.

Retention test. The retention test was conducted some 5 months after the completion of the posttraining and stress tests. The video clips, instructions, and required responses were identical for the retention test as in the earlier tests although again a different randomized order of presentation of the trials was used.

Anxiety measurement. Cox et al.'s (2003) Revised Competitive State Anxiety Inventory-2 (CSAI 2-R) was used to provide a measure of the effectiveness of the stress test scenario in inducing an increase in anxiety in the participants. Based on the original version of the test developed by Martens, Vealey, and Burton (1990), the CSAI-2 R is a 17-item inventory that measures three independent components of anxiety (viz., cognitive anxiety, somatic anxiety, and self-confidence). The CSAI 2-R was administered twice to the participants—first, to establish a baseline level, immediately prior to the completion of the posttraining test, and second, immediately after the completion of the stress test but prior to debriefing.

Explicit knowledge test. A questionnaire was used to attempt to glean what explicit knowledge each of the participants had of rules underpinning their predictions of shot direction. Three key sections of the questionnaire were completed in sequence, each involving progressively increased specificity of questioning. The first section asked the participants to list and describe, in an open-ended fashion, any general cues they used to predict where the thrower's shot was directed. The second section asked the participants to complete statements such as "The ball flew to the upper left, if . . . . ." to determine the number of general explicit rules that were used. Comparable statements were given for each of the four corners of the goal. The third section provided similar statements for completion but sought rules based specifically in relation the motion of the thrower's shoulder; for example, "The ball flew to the lower right, if the shoulder . . . ." The questionnaire took, on average, some 15 min to complete.

Training Procedures

Explicit learning group. Prior to the commencement of the training phase of the study, participants in the explicit learning group were presented with two "if–then" rules to assist them in their anticipation of shot direction. These rules were based on previous research on movement patterns of handball attackers (Schorer et al., 2007). The first rule, which related to the prediction of shot direction in the horizontal plane, was that *if* a major rotation around the axis of the throwing side shoulder is observed *then* the shot will be directed to the same side of the goal as that of the throwing arm; for example, for a right-handed thrower, the shot will go to the right side of the goal (from the goalkeeper's perspective). Conversely if there is minimal rotation around the shoulder axis, the shot will go to the opposite side of the goal as the throwing arm (e.g., for a right-handed thrower to the goalkeeper's left side). The second rule, which related to the prediction of shot direction in the vertical plane, was that if the throwing side shoulder drops and a strong flexion of the hip can be seen, then the throw will go to the lower parts of the goal, while a straight trunk and upper body is indicative of a throw to the upper regions of the goal. Both of these rules were presented to the participants verbally and with the assistance of visual aids.

The participants were then presented with a series of practice trials in which they were encouraged to apply these rules. Practice trials were presented in pairs. The first presentation in the pair consisted of a video clip similar but not identical to that included in the anticipation test with vision of the thrower occluded at either the point of release of the throw or one frame earlier or later. The task, as in the anticipation test itself, was to react as quickly and accurately as possible to predict to which of the four corners of the goal the shot was directed. The same video clip was then presented a second time but without any occlusion to make available confirmatory feedback as to the actual shot direction. To consolidate the response requirements of the task, a key press response was required to the second, unoccluded presentation just as it was for the initial, temporally occluded presentation. Throughout the 336 trials of practice on different video clips presented over Days 1 and 2 of the study, the participants in the explicit training group were constantly reminded of the two rules and encouraged to apply these rules in completing the practice tasks.

Verbal cueing group. Participants in the verbal cueing group undertook the same quantum and type of practice as those in the explicit training group except that they were given no explicit rules to assist in completion of the anticipation tasks. Consistent with a guided discovery approach, participants in this group were instead given the more general instruction to attend to the shoulder of the thrower and attempt to use this as a cue for anticipating shot direction. Previous research has shown the shoulder to be a key source of advance information for expert handball goalkeepers and a region that attracts a high percentage of the gaze behavior of these skilled players (Schorer & Baker, 2009).

Color cueing group. The training experienced by participants in the color cueing group was identical to that of those in the verbal cueing group except that those in the color cueing group also had present throughout their training a red transparent marker placed over the throwing arm shoulder for the occluded clips. The group were not informed verbally about the importance of the shoulder. Again, on both the occluded and unoccluded clips within each practice trial pair, the task of the participants was to predict impending shot direction as quickly and as accurately as possible.

Implicit learning group. During training the participants in this group were shown pairs of video clips (each occluded either at or before ball release) and were simply asked to judge whether the second clip was of the same throw or of a different throw to that seen in the first clip. This pattern comparison was therefore done entirely on the basis of advance information and no explicit reference was made at all to the likely postrelease direction of the ball. After the judgment was completed (by pressing, without time constraint, one of two possible response keys), both clips were then (re)presented without occlusion. Participants were simply instructed to use the second presentation to attempt to determine if their initial judgment was correct. This particular training approach was designed to permit the opportunity for incidental learning of the linkage between advance information and ultimate shot direction without explicit attention being drawn to either the criterion task of shot direction prediction or any rules and cues that might assist in completing this task.

Placebo group. This group watched videotapes from the TV coverage of a competitive match (a World Championships match between Germany and Sweden). They watched the tapes for a length of time in each of days 1 and 2 of the study that was equivalent to the duration of the perceptual training sessions undertaken by the explicit learning, verbal cueing, color cueing, and implicit learning groups. They were told to concentrate specifically on the behavior of the goalkeepers and were given a statement about the expected positive benefit of increased match play knowledge on goalkeeping performance.

Control group. The control group completed the pretraining, posttraining, stress, and retention tests but underwent no training/practice between these tests.

Dependent Measures and Statistical Analyses

Anticipation test. Two dependent measures were available from the anticipation test that was administered at the pretraining, posttraining, stress, and retention phases of the study—response time (RT) and response accuracy. Response time was measured as the time between ball release and key press response with any negative RT indicating that the response had been selected prior to ball release in the video clip. Response accuracy was the percentage of occasions in which the correct response key (out of the four available options) was selected. The raw RT data were initially screened to identify any participants who consistently returned either extremely fast RTs (persistent negative values) or slow RTs ($>$1 s) well outside the normal range and the data from four participants so identified were excluded from any further analyses. Outliers comprised one participant from the explicit learning group, two from the guided discovery (color cueing) group, and one from the placebo group. The remaining RT data plus the accuracy data were then tested for normality. The RT data satisfied the assumption of normality but the accuracy data did not. An arcsine transformation was consequently applied to the square root of the proportion of correct judgments for each combination of conditions to normalize the accuracy data.

To ascertain if any systematic speed–accuracy trade-off effects were evident in the response data, scatterplots of accuracy versus RT were computed for each of the four phases of the experiment and linear correlations determined. Significant positive correlations were observed in all phases ($r = .66$ at pretest, .29 at posttest and stress test, and .34 at retention-test). Understanding the accuracy data therefore required an analytical approach that partialed out the effects of differences in RT.

To account for the covariation in the speed and accuracy measures, and to assess changes in performance across the various phases of the experiment, differences in the transformed accuracy data between adjacent phases of the experiment were first calculated and then subjected to 6 $\times$ 2 (Group $\times$ Occlusion Condition) analyses of covariance with change in RT entered as a covariate. We then conducted simple contrasts between each group's performance and that of the control group followed by three specific pairwise comparisons: (1) color cueing versus verbal cueing, (2) verbal cueing versus explicit learning, and (3) explicit learning versus implicit learning. These analyses were conducted for changes occurring from (i) the pretraining test to the posttraining test, (2) the posttraining test to the retention test, and (iii) the posttraining test to the stress test. Alpha was set at .05 for all tests and effect size was determined using the partial eta squared (η_p^2) statistic.

Stress manipulation. Scores from the cognitive anxiety subscale of the CSAI-2 R inventory were compared between the posttraining and stress scenario phases of the experiment using a 6 $\times$ 2 (Group $\times$ Test phase) ANOVA.

Explicit rules formation. For each participant, the number of different informative cues identified (from the first section of the questionnaire), the average number of discrete rules of all types reported for use in predicting throws into each of the four corners (section 2), and the average number of discrete rules based specifically on the shoulder for use in predicting throws into each of the four corners (section 3) were tabulated. Each of these measures was then subjected to a one-way analysis of variance with group membership as the factor in the analysis.

Results

Anticipation Test

The mean accuracy and RT for each group in each phase of the experiment are shown in Figures 1 and 2, respectively. Simple interpretation of the changes in accuracy across test phases was precluded by a significant positive relationship between accuracy and RT at each of the test phases. At the pretest, for example, the group with the highest accuracy (the color cueing group) also had the slowest RT and, conversely, the verbal cueing group that had the poorest accuracy was also the group that had responded the quickest. Analyses treating change in RT as a covariate were therefore essential to the interpretation of the impact of the different training regimes upon accuracy.

Pretest to posttest. Analysis of covariance revealed that the covariate (RT change from pretest to posttest) was a nonsignificant predictor of accuracy change from pretest to posttest so it was removed from the analysis. The resultant analysis revealed a significant main effect of group [($F(5, 50) = 3.03$, $p < .05$, $\eta_p^2 = .23$] and nonsignificant effects for occlusion and the group-by-occlusion interaction. As can be seen in Figure 3, the largest improvements in accuracy were recorded by the verbal cueing and explicit learning groups followed by the implicit learning group. Very little change in accuracy was evident for the color cueing, placebo, and control groups.

The simple contrasts revealed that the verbal cueing group ($p = .011$) and explicit learning group ($p = .040$) improved significantly more than the control group but the color cueing, implicit learning, and placebo groups did not. Additional pairwise comparisons revealed that the verbal cueing group improved significantly more than the color cueing group ($p = .004$), and that there was no significant difference between the improvements of either the verbal

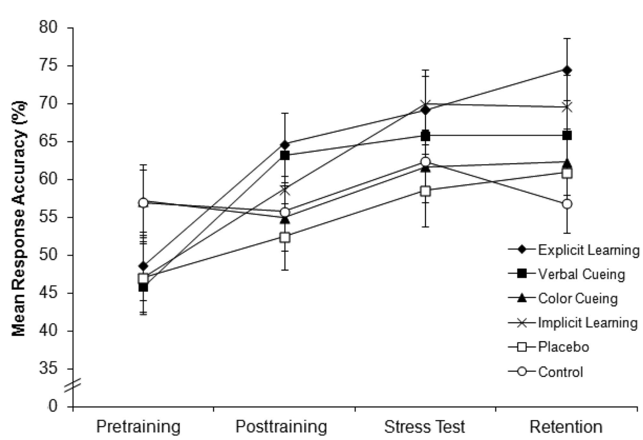

Figure 1. Mean response accuracy scores on the pretraining, posttraining, stress transfer and retention tests for each of the groups. Error bars are ± 1 standard error of the mean.

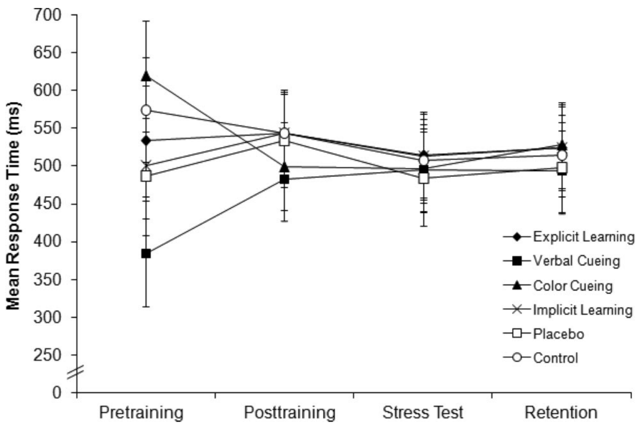

Figure 2. Mean response time (RT) on the pretraining, posttraining, stress and retention tests for each of the groups. Error bars are ± 1 standard error of the mean.

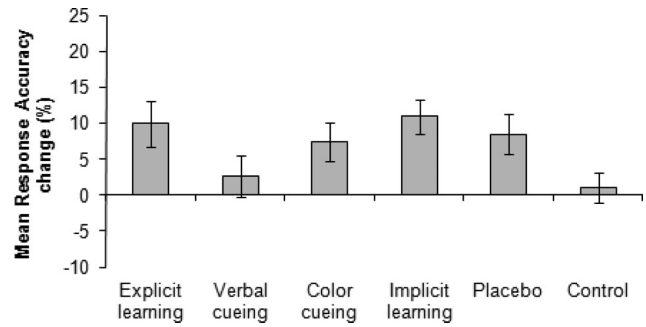

Figure 4. Mean change in response accuracy from posttest to the retention test. Error bars are ± 1 standard error of the mean.

cueing and explicit learning groups ($p = .64$) or the explicit and implicit learning groups ($p = .42$).

Posttest to retention test. Analysis of covariance revealed that the covariate (RT change from posttest to retention test) was a significant predictor of accuracy change from posttest to the retention test so it was retained in the model. The analysis revealed a significant main effect of group [$F(5, 48) = 2.69$, $p < .05$, $\eta_p^2 = .22$]. The main effect of occlusion and the group-by-occlusion interaction were nonsignificant. The simple contrasts revealed that only the implicit learning group improved significantly more than the control group from the posttest to retention test ($p = .011$). Additional pairwise comparisons revealed that the explicit learning group performed significantly better than the verbal cueing group ($p = .041$), and that there was no significant difference between the color cueing and verbal cueing groups ($p = .12$) or between the explicit learning and implicit learning groups ($p = .43$, see Figure 4).

Posttest to stress test. Analysis of covariance revealed that the covariate (RT change from posttest to stress test) was a significant predictor of accuracy change from posttest to the stress test so it was retained in the model. The analysis revealed a significant main effect of group [$F(5, 49) = 2.46$, $p < .05$, $\eta_p^2 = .20$] and of occlusion [$F(1, 49) = 7.65$, $p < .05$, $\eta_p^2 = .14$] and a nonsignificant group-by-occlusion interaction. Greater improvements in accuracy were found at the earlier occlusion condition (t1) than at the release point occlusion condition (t2). The simple contrasts revealed that the verbal cueing group improved less in the stress test than did the control group ($p = .025$) (See Figure 5). No other differences were significant. Additional pairwise comparisons revealed that the implicit learning group performed significantly better than the explicit learning group ($p = .040$), and that there was no significant difference between the color cueing and verbal cueing groups ($p = .33$) or between the verbal cueing and explicit learning groups ($p = .31$).

Stress Manipulation Check

The 6 × 2 analysis of variance revealed a significant group-by-test-phase interaction [$F(5, 50) = 5.25$, $p < .05$, $\eta_p^2 = .34$]. As expected, the five groups that were exposed to the pressure manipulation reported elevated levels of cognitive anxiety prior to the stress test whereas the cognitive anxiety for the control group was unchanged.

Explicit Rule Formation

There were no significant differences observed between the different groups on either the number of cues they identified as potentially informative [$F(5, 54) = 2.07$, $p > .05$, $\eta_p^2 = .16$] or the total number of rules they reported using for predicting shots into each of the four different corners of the goal [$F(5, 54) = 0.51$, $p > .05$, $\eta_p^2 = .05$]. Significant differences were evident, however, in the number of rules participants within each group reported using

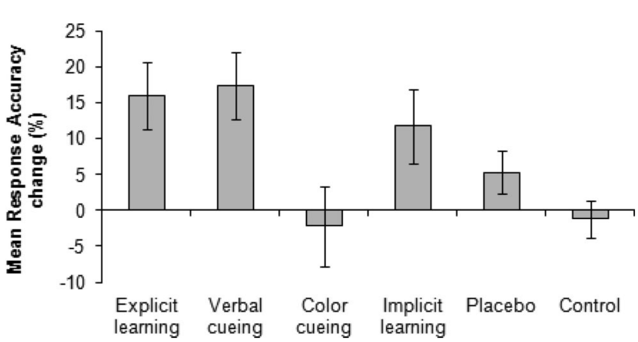

Figure 3. Mean change in response accuracy from pretest to posttest. Error bars are ± 1 standard error of the mean.

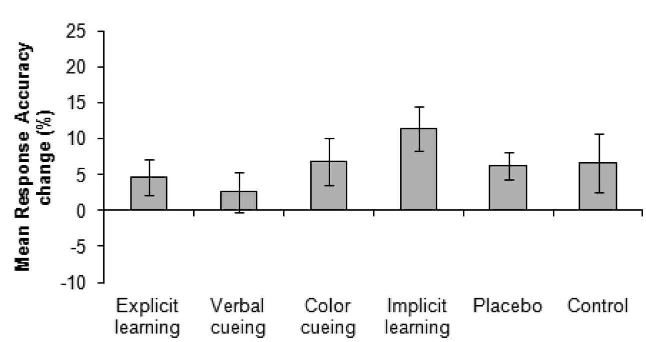

Figure 5. Mean change in response accuracy from posttest to the stress test. Error bars are ± 1 standard error of the mean.

that were based specifically on the shoulder [$F(5, 54) = 4.68$, $p < .05$, $\eta_p^2 = .30$]. The explicit training group, the control and the placebo groups reported the most rules per participant based on the motion of the shoulder whereas the verbal cueing, color cueing and implicit training groups reported the least number of rules. Post hoc testing revealed that (i) the participants in the verbal cueing group reported significantly fewer rules than participants in all other groups with the exception of the color cueing group; (ii) participants in both the verbal and color cueing groups, as well as participants in the implicit learning group, reported significantly fewer rules than participants in the control group; and (iii) the number of shoulder-based rules reported by the explicit learning, control and placebo groups was not significantly different (see Table 1 for details). There were no obvious differences in the appropriateness of the rules reported by the different groups.

Discussion

The aim of this study was to compare the efficacy of a number of different approaches that have been suggested in the perceptual training literature as offering means of improving sport-specific anticipation. The study was designed to address both the shortage of relevant studies in this area and perceived methodological issues within many of these existing studies.

Comparison was drawn between the improvements in prediction accuracy of a group given explicit rules for undertaking the task, of two guided discovery groups (verbal cueing and color cueing) given assistance in locating essential information but provided with no rules, and of a group undertaking a new method of implicit perceptual learning. The inclusion of a group given color cueing in addition to the usual verbal cueing provided the opportunity to not only determine experimentally whether color cueing works (in the sense of providing gains above and beyond those achievable simply from verbal instruction on where to look) but to also ascertain whether learning via color cueing is more implicit- or explicit-like in nature. A stress test was included to assess the robustness of the different types of learning under cognitive anxiety while a 5-month retention test was included to assess the longevity of any performance gains arising from the different training interventions.

Examination of the independent response speed and response accuracy scores for the groups across the four different occasions on which they completed the anticipation test revealed the presence of clear differences in the trading off of speed and accuracy between the different groups (see Figures 1 & 2). To attempt to correct for this, analyses were undertaken in which change in response accuracy was the key dependent measure and differences in response time were used as a covariate. Covariate analyses of this type are imperfect (e.g., they assume both a statistical and functional linear relationship between response speed and accuracy that might not be fully preserved in the anticipatory task) but are nevertheless essential to provide a measure of task performance that can be meaningfully compared between the different groups.

From the pretraining test to the posttraining test (see Figure 3), two groups (the verbal cueing group and the explicit group) produced improvements in response accuracy that were significantly superior to the changes evident in the control group. The implicit learning group also showed a positive mean gain in response accuracy over the course of the training intervention, but this improvement was not significantly greater than that experienced by the control group. In contrast, the color cueing group showed a modest reduction in response accuracy in the posttraining test compared to the pretraining assessment and a performance change with training that was significantly less than that achieved by the verbal cueing group. Both the placebo and control groups showed comparable (and minimal) changes in response accuracy across the pre- and posttraining tests, providing no evidence of any impact of expectancy effects on performance change.

The significant improvements with training that were observed in the group given verbal cueing and in the group given explicit rules to learn were consistent with both the findings of earlier studies (cf. Abernethy et al., 1999; Smeeton et al., 2005; Williams et al., 2002) and our a priori predictions. The mean improvements in performance evident in the implicit training group, while not significantly superior to those of the control group, were nevertheless in the expected direction—being both positive (cf. Farrow & Abernethy, 2002) and smaller in magnitude than the performance changes observed with explicit training (cf. Masters, 1992). With further training time or trials, it is conceivable that a significant performance increment could have been demonstrated in comparison to the control group. The poor performance of the group given color cueing was unexpected and counter to the findings of previous studies that have shown the provision of color within a guided discovery framework to be at least the equivalent of a discovery learning approach (cf. Hagemann et al., 2006). The presence of color cueing, at least as applied within the current study, appeared to have actively detracted from the performance improvement that was possible when the participants were simply verbally instructed to search the shoulder region for cues.

To be of any practical significance for the enhancement of sports performance, any improvements in anticipation skill that are induced from intensive training over a 2-day period need to be preserved over a much longer time frame. In this context the examination of the changes in performance from the posttraining test to the retention test 5 months later was particularly important, especially given that the sustainability of performance improvements due to perceptual training has been rarely examined in previous studies and, where it has been examined (e.g., Farrow & Abernethy, 2002), sustained performance improvements have usually not been evident.

In this study (see Figure 4) we found, perhaps surprisingly, no evidence of any significant loss in response accuracy over the 5-month period from the posttraining test to the retention test. It is interesting that only the implicit learning group showed greater

Table 1
Mean Number (and Standard Deviation) of General and Specific Cues and Rules Reported by Participants in Each of the Groups

Group	Cues identified	All rules per corner	Shoulder-based rules per corner
Explicit learning	2.40 (1.51)	1.75 (0.37)	1.33 (0.49)
Verbal cueing	2.10 (0.99)	1.53 (0.68)	0.55 (0.61)
Color cueing	3.50 (1.51)	1.78 (0.84)	0.93 (0.43)
Implicit learning	2.50 (0.85)	1.40 (0.52)	1.08 (0.48)
Placebo	2.80 (1.14)	1.53 (0.78)	1.33 (0.39)
Control	2.00 (1.05)	1.60 (0.52)	1.60 (0.76)

improvement/performance retention than the control group over this period. This observation is consistent with the prediction that the implicit learning group would show greatest resistance to performance loss over the extended retention period. Earlier research from the cognitive domain (e.g., Allen & Reber, 1980) has suggested that one of the advantages of implicit learning approaches is improved retention of task-relevant information over an extended period.

The stress test was included in the design of the study with the express purpose of examining the proposition (from Masters, 1992) that those groups that learned the anticipatory skill under more implicit conditions would show more robust performance under stress than those groups who learned the skill through explicit rule formation. The evidence from the data collected using the CSAI 2-R inventory indicated that the evaluative scenario used in the stress test had the desired effect of increasing the cognitive anxiety of the participants. However, despite an increase in the levels of stress experienced by the participants there was no evidence (see Figure 5) of performance decrements under stress (i.e., "choking")—indeed all groups marginally improved their performance in the anticipation test undertaken in the stress scenario phase of the study compared to the test undertaken posttraining.

The close temporal proximity of the anticipation tests undertaken in the stress and posttraining phases of the study may provide an explanation as to why performance decrements under stress were not observed. It is possible that some learning on the test itself (even in the absence of any form of augmented feedback) may have occurred that offset or masked any negative performance consequences arising from the evaluative stress. Given this possibility, the comparison of the changes in response accuracy for each of the training groups to the performance of the control group provides an important metric of the stress-resilience of the different groups (and the forms of learning they undertook). It is noteworthy then that only the implicit learning group (see Figure 5) produced changes in response accuracy from before to after the stress test that were superior to those of the control group. This finding is consistent with earlier work in motor learning (e.g., Masters, 1992) and in the perceptual training of anticipation (Smeeton et al., 2005) that demonstrates that the stress-resilience of implicit forms of learning is superior to that of more explicit modes of instruction and training.

Our a priori predictions about the performance of the different training groups on the stress test were predicated on the assumption that the learning and control of the designated implicit learning group and of the two discovery learning groups would be generally more implicit in nature, as reflected by the development and use of fewer explicit rules, than would be the case for the other groups in the study, especially the explicit learning group. The questionnaire we used to extract measures of explicit rule formation, however, revealed some conflicting information. No significant differences between the groups were evident in terms of either the number of general cues used or the number of general rules that were formed based on cues from all different aspects of the opponent's movements. Differences were apparent, however, on the number of explicit rules that the different groups had formed in relation to the motion of the shoulder—the cue that is known to be most pertinent for anticipation in handball goalkeeping and the one most frequently sampled by experts in this task domain (Schorer & Baker, 2009; Schorer et al., 2007).

The differences observed in the number of discrete shoulder-based rules that were reported by each group were only partially supportive of our a priori predictions. Consistent with our expectations, those participants in the control groups and those in the explicit training group reported the most rules and those training under verbal and color cueing and implicit learning conditions reported the lowest number of rules (see Table 1). Counter to our a priori expectations, the lowest number of rules relating to the shoulder was reported by the two guided discovery groups rather than by the implicit learning group—the verbal cueing group reported the lowest number of rules and significantly fewer than all other groups except the color cueing group. (In contrast, the implicit learning group reported the lowest number of rules of all types [including rules based on cues additional to the shoulder] although this number was not significantly different to that of the other groups.) Again counter to our original prediction, there was no clear relationship evident between the number of rules reported and performance on the stress test.

The data obtained from the questionnaire designed to assess explicit rule knowledge and formation highlight some particular challenges with determining the extent to which the learning undertaken in different groups is indeed (primarily) implicit or explicit. While questionnaires are regularly used to attempt to verify that implicit treatments have been effective in resulting in less verbalizable rule formation than explicit approaches (e.g., see Farrow & Abernethy, 2002; Masters, 1992; Smeeton et al., 2005), the measurement approach is less than ideal. The current study highlights two particular problems with this approach.

One problem with the questionnaire approach to explicit rule measurement is that the indication of how many rules are formed by each group is very dependent upon what is asked and especially the level of specificity within the question. As Table 1 illustrates, quite different estimates of rule formation arise if the question is asked in terms of what cues are used, what rules of all types are used, or what rules related to specific cues are used. Different responses are also likely to be generated if the participant is asked to name rules they know about for the task as opposed to specify what rules they actually used in completing the task.

A second, related issue with using questionnaires to attempt to infer explicit processing is that a measure of the number of rules that a participant knows is still likely to be only a poor proxy for the extent to which explicit processes are actually engaged during task completion. For example, one explicit rule used on each and every trial will generate an indicator of low explicit engagement and many explicit rules used only sporadically and only on some trials will generate an indication of high explicit engagement when, in both cases, the converse assessment of explicit processing engagement would be the appropriate one. Questionnaire data as a means of confirming explicit processing engagement should clearly be used with considerable caution and there is an urgent need for more direct and veridical measures of explicit processing to be developed.

These issues notwithstanding, there are a number of conclusions that can be drawn from the current study which may help consolidate and advance understanding of the training of perceptual skills such as anticipation. First, it is apparent that anticipatory skills, at least as they are assessed in a laboratory setting, can be improved by a variety of different training methods. This study provides further evidence as to the efficacy of not only traditional explicit instruction but also guided discovery (via verbal cueing) and perhaps also implicit learning in enhancing anticipatory skill in a sustainable way. The implicit approach developed here was inferior to the explicit and verbal cueing approaches in securing significant pre- to posttraining improvements but superior in promoting the preservation of performance through to 5-month retention and under evaluative stress. Evidence from other studies that have demonstrated positive transfer of anticipatory skill from laboratory training to on-court performance (e.g., Farrow & Abernethy, 2002; Williams, Ward, Smeeton, & Allen, 2004; Williams et al., 2002, 2003) provides reason for optimism that such transfer might also be forthcoming for the kinds of training regimes and task domains examined in this study. Nevertheless the specific inclusion in future studies of a transfer test that requires the production an actual (coupled) goal-keeping movement response would provide additional assurance that the gains in anticipatory skill evident on the (uncoupled) laboratory measures we used can be transferred for functional benefit on court (cf. Mann, Abernethy, & Farrow, 2010; van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008).

Second, the study indicates that color cueing, at least as presented here, was not advantageous. Indeed providing color cueing to aid in directing attention to the important motion of the shoulder produced consistently poorer performance than a simple verbal direction to attend to this area. It appeared that, paradoxically, highlighting the key cue with color resulted in less formation of rules related to the shoulder but appeared to promote increased searching for cues from other areas of the display and increased formation of rules based on cues other than the shoulder (cf. data in columns 1 and 2 with column 3 in Table 1). As there was little evidence from existing studies of color cueing providing a benefit beyond that achievable through discovery learning (Hagemann et al., 2006), and the results from this study suggest color cueing may actually detract from the benefits of verbal cueing, any use of color cueing within perceptual training regimes should be done with caution. If color cueing is to be used effectively it will clearly require approaches different to those trialed here.

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