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Decision Making in Sports: Influence of Complexity on Implicit and Explicit Learning

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Abstract

This paper analyzes the implicit and explicit learning distinction of tactical decision making in ball games. It is argued that implicitly learned decisions are advantageous in low-complexity situations and explicitly learned decisions are advantageous in high-complexity situations. Four experiments were carried out in low-complexity and high-complexity situations in handball, basketball, and volleyball. The results suggest that in low-complexity situations implicit learners are superior to explicit learners, and in high-complexity situations the opposite is true. These results, in sports-specific situations, are consistent with recent research that shows the ecological rationality of human behavior. Practical applications are drawn from the results for training in ball games.

Key Words: complexity, decision making, dual-process theories, implicit learning, explicit learning

Dual-process theories are commonly used to describe decision-making processes and implicit/explicit learning in sports (Chaiken & Trope, 1999; Masters, 2000; Raab, 2002a). The distinction between implicit and explicit motor learning is a well-known example that has recently influenced the sports psychology debate in an issue of the International Journal of Sport Psychology (Beek, 2000; Bennett, 2000; Masters, 2000).

In this paper, the distinction of implicit and explicit learning will be used to show that the unquestioned assumption of the primacy of one process cannot hold (Kirsner & Speelman, 1998; Sun, Merrill, & Peterson, 2001). Therefore, task-specific aspects will be discussed and empirically evaluated. Implicit learning is defined as a "nonintentional, automatic acquisition of knowledge about structural relations between objects or events" (Frensch, 1998, p. 76), and explicit learning as an intentional acquisition that results in verbalizable knowledge (O¥Brien-Malone & Maybery, 1998). Each of these processes leads to improvements in behavior. Note that within the sports context implicit learning must be further differentiated into implicit motor learning, that is, how to produce a specific movement; and into implicit cognitive learning, that is, how to build judgments about the relation between stimuli and what movement should be carried out (Masters, Law, & Maxwell, 2002, p. 130). In this paper the distinction between

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motor-linked and judgment-linked implicit learning is used and the focus will be on the cognitive judgment-linked learning aspects. It has been questioned whether implicit motor learning is always superior to explicit motor learning in the sports context (Beek, 2000; Bennett, 2000). Evidence will be presented from both the implicit/explicit *motor* skill learning research and the implicit/explicit *cognitive* skill learning research that the dissociation of implicit and explicit processing neglects the environment in which they are used (Rossetti & Revonsuo, 2000). The distinction of motor skill learning versus cognitive skill learning distinguishes research that focuses on how a movement is carried out (motor skill) from research on what movement is carried out (cognitive skill). Research on explicit and implicit motor learning primarily shows the advantage of implicit learning over explicit learning, or more simply, that movements can be learned implicitly (Liao & Masters, 2001; Masters, 2000; Maxwell, Masters, & Evers, 2000; Shea, Wulf, Whitacre, & Park, 2001). For instance, Shea et al. (2001) argued that based on their experiments it can be concluded that withholding information concerning regularities in the task demands may be more beneficial than providing this information. In addition, Masters (2000, p. 538) argued that "the weight of evidence in implicit motor learning research suggests that there are benefits if motor skills can be learned implicitly." From these and related findings, practical applications are drawn (Magill, 1998; McMorris, 1998), although they may not be appropriate for every situation encountered.

If these findings can lead us to the claim that implicit motor learning is better independent of the situation in which it is performed, then this concept would seem to fit the *less-is-better* ideology discussed by Goldstein and Gigerenzer (2002). This ideology ignores any adaptiveness between the environment and cognitive or sensorimotor processes. The same argument holds for decision-making research in the cognitive domain. For instance, Reber (1989) assumes a primacy of implicit processes in the context of artificial grammar learning, because it operates naturally and undetected when dealing with complex environments. Others have proposed theories (e.g., Evans, 1989; Sloman, 1996) that nonheuristic strategies, such as regression-based decision strategies, result in better decisions than heuristic strategies, such as the "Take-The-Best" heuristic, which relies on only one or a few reasons to make a decision (Gigerenzer & Todd, 1999). Again, if more information to make a decision is better than less information, independent of the situation, than this would be called a more-is-better ideology. The *more-is-better* ideology in the cognitive domain ignores the ecological rationality of cognitive and sensorimotor strategies (Gigerenzer, Todd, & The ABC Research Group, 1999).

In sports, research concerning the issue of verbalizable knowledge and decision-making performance is rare. One exception is expertise research, which concentrates on the description of the correlation between knowledge and performance. For instance, French and Thomas (1987) found that skilled children who possessed more basketball knowledge demonstrated better performance in actual game situations. However, it is unclear how to interpret this correlation (Wickens, 1992). The "more-is-better" emphasis in these reports indicates that verbalizable knowledge facilitates decision making. However, there is also evidence showing that verbalizable knowledge does not facilitate decision making (Broadbent, Fitzgerald, & Broadbent, 1988; but see Buchner, Funke, and Berry, 1995 for methodological concerns). This paper will provide empirical evidence to support the claim that implicit and explicit *cognitive* processes are task specific in tactical sports decisions. Studying learning processes in situations of varying complexity will allow us to evaluate the primacy of implicit or explicit cognitive learning for making fast and appropriate tactical decisions.

Learning and Complexity

There are several reviews of the implicit/explicit distinction in the cognitive domain (Berry & Cock, 1998; Reber, 1989; Seger, 1994; Stadler & Frensch, 1998) and its relation to the complexity of a situation (Gomez, 1997). For our purposes, a more exact specification of implicit and explicit learning, complexity, and the interaction of learning modes and complexity is required.

Implicit and Explicit Learning

Implicit and explicit learning, as defined on the continuum of intentionality, may be best specified by looking at the learning situation itself. Situations in which actions are incidental in nature engender implicit learning, whereas situations in which actions are intentional in nature engender explicit learning.

Incidental learning (Perrig, 1996; Thorndike & Rock, 1934, p. 1) is learning in a situation without an intention to learn, or without explicit knowledge about the underlying rule structure of the situation. A commonly used paradigm to study the effects of implicit and explicit cognitive learning is the artificial grammar paradigm. The task in the artificial grammar paradigm is to learn artificial words (e.g., TXSUVW) and then to judge whether those words, as well as new words, are grammatically correct or incorrect. Participants are often capable of correctly judging the grammar of old and new words without being able to verbalize any rules underlying the structure of the words.

To promote implicit processing, a cover story is used that leads participants to believe that they are taking part in a memory task, whereas the underlying goal is for the participants to learn artificial grammar rules as part of an artificial grammar task (Reber, 1989). To promote explicit learning, participants are instructed to discover (or are trained with) the rules defining the structure of the given task (Singer, Lidor, & Cauraugh, 1993). Intentional learning takes place when instructions are used that identify relationships in the task or the goals of the learning process (Reber). To distinguish implicit learning from explicit processes, a number of features are assigned to implicit learning, such as fast processing, robust against forgetting, small inter- and intra-individual differences, and nonverbalizable knowledge, among others (Reber).

Complexity

Complexity, for our purposes, is defined as an environmental complexity (Streufert & Castore, 1971), and is manipulated by varying the amount and connectivity of available information (Siemann & Gebhardt, 1996; Wood, 1986). Other procedures such as using dual tasks (DeShon & Alexander, 1996; Masters, 2000), transferring tasks (Mathews, Buss, Stanley, Blanchard-Fields, Cho, & Druhan, 1989; Reber, 1967), adding situational factors such as time pressure or emotional stress (Masters, 1992), or using different affective states (Rathus, Reber,

Manza, & Kushner, 1994) will not be discussed in this paper. In tactical decisions, varying the number of choices and attributes is a useful means of manipulating the cognitive complexity of a situation. For perceptual manipulations, space-time parameters (e.g., distances and moves of players) can also be varied.

One way to formally describe the tactical situations of different complexity is with graphs (Raab, 2002a). For a defined sports-game situation, a graph can represent the decision options from the perspective of one player (e.g., in handball, to pass to a team member or to throw to the goal) and the attributes that influence this decision (e.g., the behavior of one's teammates and of the opposing team's defense players). The representation of a situation is combined with the possible options in a situation. These combinations are defined as if-then rules (McPherson & Thomas, 1989) what decision is optimal in specific combination of situational variables.

The complexity of a situation can be calculated by using the graphs to determine a "cyclomatic number" (McCabe, 1976) of cognitive manipulations, by counting the number of components (options and attributes) and the number of connections between them (see Raab, 2002a, for a detailed description). Therefore, the complexity of situation increases when the number of options rises and their detectable differences decrease, and when the number of attributes used to define a situation and the relation between decisions and situations increases. In addition, the perceptual space-time relations (e.g., distance between players) of the situations are smaller in high-complexity situations, compared to low-complexity situations.

The complexity of visual displays can also be operationalized in graphs (Raab, 2002a), in which the number of cues and their distribution can be functionally described. For instance, the distance between defense and attack players serves as an important cue to decide to whom to allocate the ball. However, this task can be much more complicated when the defense plays a space defense (distribution of defense players over space) than when a "one-on-one" defense (assignment of one defense player to one attack player) is mounted.

Interaction between Learning and Complexity

Few studies have been conducted on the interaction between implicit and explicit cognitive learning, on the one hand, and complexity, on the other. To my knowledge, there is no research into the interaction specifically in the sports domain. Yet, there is evidence that situation variables enter the decision making process (Bard, Fleury, & Goulet, 1994) and there are different attentional costs in different complex situations. In addition, implicit and explicit decision training (called *bottom-up* and *top-down* processes by Vickers, Livingston, Umeris-Bohnert, & Holden 1999) for intermediate and advanced baseball hitters has shown that explicit decision training results in lower performance during acquisition but results in higher performance during transfer.

Research from cognitive psychology may provide information to generate assumptions about the interaction between different modes of learning and complexity. For instance, Reber (1989) - as mentioned above - and Reber and Lewis (1977), in their artificial grammar learning experiments, found that implicit learning is the primary process when dealing with complex environments. Johnstone and Shanks (2001, p. 96, for an overview) suggested that there is evidence that implicit learning is superior in high-complexity situations (Dienes, Broadbent, & Berry, 1991; Mathews et al., 1989; Reber & Allen, 1978; Reber, Kassin, Lewis, & Cantor, 1980). However, there is counter evidence that explicit learning is better in these types of situations (DeShon & Alexander, 1996; Dulany, Carlson, & Dewey, 1984; Gomez, 1997). Gomez showed, by comparing participants with low and high knowledge in complex and transfer tests, that in artificial grammar tasks, explicit knowledge about letter patterns appears to be more important for learning high-complexity tasks. She found that participants performed better with more explicit knowledge in these tasks and in the transfer condition.

The finding of beneficial effects of more explicit knowledge in quite complex situations is in line with the results reported earlier by McPherson and Thomas (1989). In sports such as basketball, information search is necessary to decide, for instance, between four or more options available to a playmaker. In addition, decisions are bound to the situation of high time pressure and lack of sufficient available information (Gigerenzer et al., 1999). The amount and quality of the selected information (cue validity) affects sports performance (Ripoll, 1991). Therefore, it can be assumed that more explicit information may not always be better. It can be speculated that implicit learning may be effective in low-complexity situations where information can be extracted easily. When additional information, or the instructions from a coach, are added during the exploration of a situation it may cause a condition in which different pieces of information compete with each other and, therefore, decrease the performance. On the other hand, in high-complexity situations, explicit knowledge from coaches guides players to look for the "information rich areas" (Magill, 1998) and may enhance the performance because in such situations, what cue is picked up is of more importance. There is also evidence that explicit instruction regarding the best cues to look for in tennis is not as effective as implicit cuing (Farrow & Abernethy, 2002).

Four experiments were conducted to in an attempt to reconcile the heterogeneous findings of the interaction of implicit and explicit learning processes and complexity in the decision making of athletes in tactical team sports. These experiments were designed to test the hypothesis that implicit learning is better in low-complexity situations and explicit learning is better in high-complexity situations.

The design of each experiment necessitated the use of implicit and explicit learning groups in a between-groups design at one complexity level. To ensure that the implicit learning group did not recognize the real goal of the task, not only was a cover story required, but there could also be no pretest on decision making. To evaluate the learning of the implicit and explicit groups without a pretest, a control group that took part only in the decision-making test was included, to differentiate what participants bring to the experiment and what results from the learning process (see Bennett, 2000, p. 543, for a discussion on methodological issues).

The low-complexity and high-complexity situations were separated between experiments. To increase the generalizability of the results multiple experiments in different sports were carried out. Therefore, handball, basketball, and volleyball situations were used to allow for a general account of the interaction between implicit/explicit learning processes and complexity of the situations for tactical decisions in ball games.

EXPERIMENT 1

This experiment was designed to explore the effects of the implicit and explicit learning of if-then relations between stimuli and tactical decisions in a low-complexity situation in basketball. Because the situation was of low complexity, the implicit acquisition of if-then rules should result in greater decision-making quality than the explicit acquisition of these rules.

METHOD

Participants

Fifty-two participants, 26 females and 26 males, between 20 and 28 years old (mean age = 25.5,) were randomly assigned to three groups (an implicit group, an explicit group, and a control group). They were undergraduate students with no experience in basketball at the sports club level. All participants in this study provided informed consent.

Description and Selection of Decision Situations

The situation used in this experiment is called "center-rotation" in basketball: the right-guard player possesses the ball and has four options - pass to the rotating center, pass to the post, pass to the playmaker, or shoot to the basket. Experts were consulted to define the if-then rules so that only one option was correct in each variation of the defined situation. The variations differed with respect to the spatial-temporal organization of the offense and defense players. The first if-then rule (Rule 1), for example, described a situation in which the right-guard player should shoot to the basket: "IF the defense player is far away, THEN shoot to the basket." Rule 2 (IF the defense player does not follow the moving post player, THEN pass to the post player), Rule 3 (IF the defense player does not take over the moving center, THEN pass to the center player), and Rule 4 (IF the defense player does not allow passing to the post, center, or shooting to the basket, THEN pass to the playmaker) describe the other options.

Video clips of the IF-THEN scenarios were selected through four validation procedures that included two expert ratings, an item analysis, and external validation. The expert ratings were provided by two experts who assigned videotaped situations to one of the four rules (narrowing down a pool from 600 to 400 clips). Another two experts rated the 400 clips regarding their similarity to real competitions. The 100 most competition-like clips (25 from each rule) were used for the item analysis in which 20 participants of a basketball course (Institute for Sport and Sport Sciences, University of Heidelberg) had to choose the appropriate decision for the displayed situation out of the four options for each video clip. The performances of the decisions in the test were compared with the expert ratings (lecturer of the course) of the performances in a course training competition (test and competition correlation was $r = 0.86$).

Apparatus and Material

A Heidelberg Video test for tactical decisions (HVD) was used (Raab, 2002a). At the end of each video clip, prior to the decision of the right-guard player, the video scene was frozen for one second. Participants had to stand (straddle) on two ground mats in a ready position from which they had to move to one of four ground mats in front of them. The four ground mats represented the four options (shoot to the basket, pass to the playmaker, pass to the center, and pass to the post) from the learned if-then rules. The ground mats were organized so that, for instance, the ground mat that represented the pass to the playmaker was the far-left ground mat (see Figure 1) because from the perspective of the right wing player in the video, that would be the far-left option. The task required the participants to move as quickly as possible to the mat that corresponded with the best option available to the right-guard player on the video clip (see Figure 1). Ground mats were connected to an interface to measure decision time in milliseconds and identify the options chosen by the participants. Decision time and accuracy were calculated by means of a computer. Signals from the videotape for each video clip were interfaced with a computer clock.

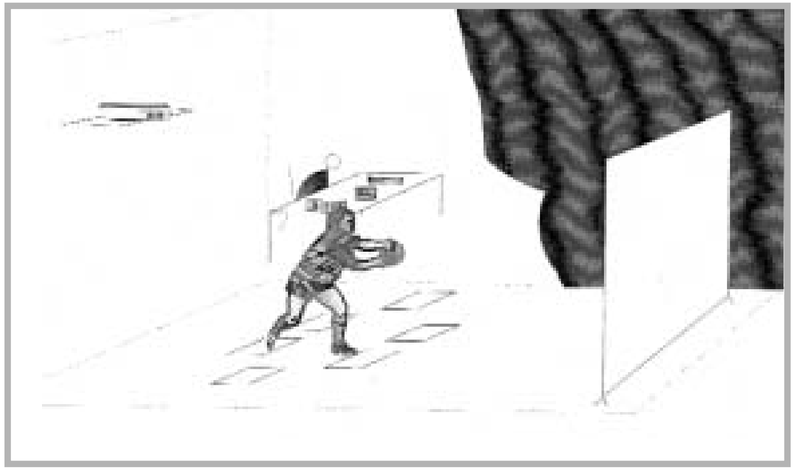

Figure 1. Test situation: Heidelberg Video Test (HVD) for tactical decisions in basketball. The participant stands on two mats and from there moves as quickly as possible to one of four mats that represent the options available to a marked player on a video clip. The mats and the video signals are connected with an interface and a computer monitored by the investigator to calculate decision time (milliseconds) and decision quality (percentage of correct decisions).

The rationale behind using a video test with real movements to express participants' decisions was threefold. First, an ecologically valid test was desired, as argued in the natural decision-making literature (see Helsen & Powells, 1993; Williams, Davids, Burwitz, & Williams, 1993; Raab, 2002b, and the special issue of the *Journal of Behavioral Decision Making, 14*, 2001). Second, the best possible transfer between the learning and test phases (e.g., transfer-appropriate processing) needed to be ensured. Therefore, the imitation of the decision-based movements of the displayed guard player for the learning and test phases was used. Third, the use of multi-modal representations of tactical decisions, which can facilitate learning and recall by action-based memory (Engelkamp, 1998), was introduced.

The material presented in the HVD was validated as described above. Each video clip was approximately five seconds long and showed a typical basketball situation called "rotation of center," in which the guard player on the right side (marked with a red shirt) has to make a decision. The situation that each video clip showed offered four possible decisions, of which one was the best. Of the 50 video clips in every session, 25 showed correct decisions and 25 showed incorrect decisions. In the video clips with correct decisions, the ball always ended in the basket, whereas in the video clips with incorrect decisions, the ball was either caught by the defense or missed the basket. Both forms of non-success were labeled incorrect decisions because they did not result in a point. The video clips of correct and incorrect decisions were presented in random order. The percentage of correct decisions was calculated compared to chance level (25%).

Procedures

Practice. The training took place over a four-week period in four sessions (one session per week) to mirror the learning procedures of beginners in real sports situations. A total of 200 video clips were viewed during the four sessions over four weeks (50 per week). The implicit and explicit learning procedure differed only in terms of the instructional set (Reber, 1967). The control group did not take part in the learning; they participated only in the test to ensure a baseline for decision making in the test. The implicit and explicit groups practiced the if-then relations of a player's behavior with respect to variations in a basketball game situation that was presented on the video clips.

At the beginning of each training session, the explicit learning group read a written example and watched three video clips of each if-then rule. Implicit learners read instructions that informed them that they were taking part in a memory test. They were instructed to memorize 5 out of every 10 decisions made by a marked player on the video clips for a partial-recall test (decisions 1 to 5, or 6 to 10). In every session with 50 video clips, the partial-recall test was applied five times for every participant. Training took place in small groups ($n = 4$), which were separated by partition walls. Participants were asked to imitate the actions of the right-guard player in the video clip by stepping on the ground mats arranged around them.

Testing

Two tests were run after the training sessions to check the efficiency of implicit and explicit learning in tactical decisions. The first, which occurred one day after the last training session, was an indirect test to measure decision quality and decision time. This test involved the use of the HVD for tactical decisions. The instruction on how to decide on options was balanced for speed-accuracy effects ("decide as quickly and accurately as possible").

The second test, which was given four weeks after the last training session, was a retention test in which no feedback was received. The retention test was identical to the post test, that is, the same video clips were shown. The procedure of the post test was repeated for the retention test; except for a questionnaire for explicit knowledge at the end of the retention test, and the debriefing at the end of the session. No HVD pretest was used to access prior knowledge about the situations. This was necessary to enable the implicit group to acquire the structure of the situation without knowing the aim of the experiment. As a control for any unwanted prior knowledge, information on past sports game experience and the amount of practice in sports was collected. After a warm-up period of 20 scenes, the HVD involved 50 played situations. A questionnaire at the end of the retention test, with both open-ended questions (Wulf & Schmidt, 1997) and a multiple choice section (Squire & Frambach, 1990, p. 113), revealed the real purpose of the learning sessions and assessed whether the participants were able to verbalize the structure of the given situations. The different options for each situation were verbally and visually presented, and participants were asked to describe how and why specific decisions were made. All answers were transformed into a scale of qualitative knowledge about the structure of the situation (0 to 3, where 3 means the maximum) and a scale of quantitative knowledge (Likert scale 0 to 9, where the maximum is 9). The scale for qualitative knowledge was built by the transformation of the participants' answers (expert analysis), based on whether they could be attributed to the "syntax" structure of the situation (the IF-THEN structure), or to perceptual-space relations. For instance, if a participant answered "I passed to the center player when a defense player did not guard him," then his answer refers to the syntax of the structure. However, if a participant's answer was "The center was free, so I played to him," then this answer was attributed to the perceptual-space relations of the situation. The experts also had to rate how much the total answer on the scale of 0 to 3 reflects the category (e.g., syntax of the structure or perceptual-space relations) chosen by the expert.

RESULTS

The median was calculated for decision time and the arithmetic mean for decision quality. Outlier reduction was carried out through the windsoring method. Windsoring replaces extreme scores by the value that is two standard deviations above the mean in every trial (about 2% of the data; see Gomez, 1997, for reaction time truncation in implicit learning). For all inferential statistical tests, the significance criterion was set at $\alpha = 0.05$.

Implicit Learning

The implicit group (M = 45.0%, SD = 8.85) was superior to the explicit group (M = 37.6%, SD = 8.56) in the number of correct decisions. In addition, both the implicit and explicit group performances were above chance level (25% by four options) as indicated by the means, whereas the control group was marginally above chance level (M = 30.5%, SD = 10.04). Two 3 X 2 ANOVAs (Groups X Tests) with repeated measures on the last factor were run for decision quality and decision time. For decision quality, the group main effect was significant ($F_{(2,49)}$ = 11.53; $p < 0.01$). Post hoc analyses (Scheffé) indicated that the control group had a lower level of decision quality than the implicit and explicit groups ($p < 0.01$), and that the implicit group was significantly better than the explicit group ($p < 0.05$).

The group main effect for decision time was significant ($F(2,49) = 3.81$; $p < 0.05$). However, no differences could be found in post hoc analyses between the implicit and explicit group for decision time. No main effect for test could be found for decision time and number of correct decisions. In addition, no interaction between groups and the test could be found for the number of decisions (or decision time).

Explicit Knowledge

The analysis of the questionnaire revealed more quantitative knowledge by the explicit group (M = 5.21, SD = 2.44), compared to the implicit group (M = 2.65, SD = 1.69) and the control group (M = 2.02, SD = 1.32), but this did not reach a significant level in an ANOVA with the three groups on the number of if-then rules known. The low level (the maximum was 9 points) of the quantitative rule-specific knowledge of the implicit group shows that participants in this group learned at least partially implicitly. The learning of this group was implicit because they could not verbalize much knowledge about the underlying if-then rules of the situations. The score on verbalizable knowledge for the implicit group was almost half that of the explicit group. In addition, the learning of if-then rules was nonintentional because all participants of the implicit group believed in the memory cover story, as the debriefing showed. An if-then rule-specific analysis of the verbalized knowledge revealed that the knowledge was mainly based on Rules 1 and 2 (Rule 1: the if-then rule that defines when to throw to the basket; Rule 2: the if-then rule that defines when to pass the ball to the post player). Rules 1 and 2 were both verbalized by all of the explicit participants, but only by less than 10% of the participants of the implicit group. However, no differences could be found in the qualitative knowledge between the implicit and the explicit group. In both the post test and the retention test, the difference in decision accuracy between the explicit and the implicit group was greater in Rules 1 and 2, compared to Rules 3 and 4.

DISCUSSION

Implicit learners were superior to explicit learners in decision quality, but not in decision time. Because decision quality constitutes the more sensitive variable to judge the amount of learned if-then relations, these results demonstrate that implicit learners produce better decisions in low-complexity situations. Speed-accuracy effects between groups could not be found, as expected, due to the balanced instructions to decide as quickly and accurately as possible.

To ensure that the treatment of the implicit group resulted in implicit learning, in addition to the verbalizable knowledge test and the debriefing, more detailed analyses of the HVD were carried out. The implicit learning literature lists robustness (robust against forgetting) and small interindividual differences as features of the learning output (Berry & Dienes, 1993). The learning was robust against forgetting, which could be shown by the absence of a significant decrease in decision quality from the post test to the retention test after another four weeks. The standard deviation for the explicit group pooled for the post test and the retention test was 13.24% (a deviation from the mean percentage of correct decisions), compared to 8.96% for the implicit group, indicating smaller interindividual differences in the implicit group.

Furthermore, the analysis of the speed-accuracy effect does not show any distribution that could be attributed to a specific strategy, entailing processing some video clips more slowly and in an explicit manner and some clips more quickly and implicitly. In contrast, the expected normal distribution of accuracy and decision time was found for all decisions and also in a rule-specific analysis. The implicit learning group was superior in the number of correct decisions. These findings of better decisions by the implicit group, compared to the explicit group, contradict the results of Reber and Allen (1978) obtained in artificial grammar learning. They found that the explicit group was superior in low-complexity situations. The advantage of the implicit group in acquisition and retention is also not in line with the findings in the implicit motor literature (Maxwell et al., 2000). Maxwell et al. showed that explicit motor learners were superior in acquisition but found no differences in a delayed retention test. However, because the focus in this study is more on cognitive implicit learning, these effects should be replicated before the differences from other studies are emphasized.

To overcome possible sport-specific (i.e., basketball-specific) effects, in Experiment 2 the sports game handball was used to generalize the findings of Experiment 1. In addition, it could be argued that the results of Experiment 1 are a result of the very short timeframe in basketball in which decisions have to be made. Such decision situations may favor implicit processes because implicit processes are assumed to be faster and, therefore, could be better applied to a fast decision. For instance, Reber (1989) argued that implicit learning features include "fast processing." If the movements in the video clips presented are fast (e.g., the center rotation situation in basketball) then it may be that the selection of the situation and the duration of the video clip itself favor the implicit learning processes in the test situation. To rule out this possible effect, in Experiment 2 participants watched longer video clips during training and test (7 to 10 seconds) to allow for an extended processing of information. In addition, situations from handball, where decisions to whom to pass the ball are slower, were used.

EXPERIMENT 2

The first purpose of Experiment 2 was to replicate the findings of Experiment 1 - that implicit learners are superior in decision quality, compared to explicit learners - even if the time for extended processing was increased. The second purpose of Experiment 2 was to extend the results of Experiment 1 to a different sports context. Therefore, in Experiment 2 a handball situation was used.

METHOD

Participants

Fifty-three female and male undergraduate students between 19 and 30 years old (mean age = 27.8,) were randomly assigned to implicit, explicit, and control groups. None had participated in Experiment 1, and all participants provided informed consent.

Description and Selection of Decision Situations

The handball situation "come in from the left side," was used, which included four if-then alternatives, this time from the perspective of the playmaker making the decision. Again, experts developed four rules for this situation. The four if-then rules had to be correctly mapped to four available options: pass the ball to the wing player on the left side (Rule 1), to the half-back player on the left side (Rule 2), to the center-front (pivot) player (Rule 3), or to the half-back player on the right side (Rule 4).

Apparatus and Material

The HVD was adapted so that the ground mats now represented handball players' positions. The same validation procedures for the video clips of Experiment 1 were applied to the handball situation. The spatial configuration of the mats was related to the positions of the players on the display. To express their decisions, participants had to move on the mat in the direction of the player they wanted to pass to and imitate the pass movement.

Procedure

No changes were made regarding the length or type of practice, compared to Experiment 1. Again, without a pretest, four weeks of practice (including 200 video clips, 50 video clips per week) were followed by a post test and a retention test (four weeks later). The previous order of tests, from HVD to questionnaire, was used again.

RESULTS

The same procedure of outlier reduction from Experiment 1 was applied to Experiment 2. The transformation of explicit knowledge answers was again made to scales of quantitative knowledge (a maximum of 9 points) and qualitative knowledge (0 to 3 points).

Implicit Learning

Implicit learners (M = 59.38%, SD = 10.56) tended to be superior to explicit learners (M = 44.72%, SD = 13.24) in regard to decision quality. For the implicit and the explicit groups, the decision quality was far above chance level (25% of four equally presented options). Two 3 X 2 ANOVAs (Groups X Tests) were carried out for decision quality and decision time. There were no main significant differences among the groups for decision quality. Rule-specific analyses showed that for Rule 1 and Rule 2, decision quality (Rule 1: $F_{(2,50)} = 6.57$; $p < 0.01$; Rule 2: $F_{(2,50)} = 3.45$; $p > 0.05$) and decision time (Rule 1: $F_{(2,50)} = 6.10$; $p < 0.01$; Rule 2: $F_{(2,50)} = 2.92$; $p = 0.06$) differed significantly, as expected. The control group, again, had lower decision quality than the experimental groups (Scheffé, $p < 0.05$). No significant changes of effects between the treatment groups could be found in the retention test, and no interaction, indicating the stability of the learned decisions. Again, implicit learners were significantly better in Rule 1 and Rule 2, compared to the explicit group in acquisition and retention. No significant difference could be found for Rule 3 and Rule 4.

Explicit Knowledge

The knowledge of explicit learners was significantly greater than that of implicit learners and the control group ($F_{(2,50)} = 13.01$; $p < 0.01$) for the scale of quantitative knowledge (explicit group: M = 6.52, SD = 1.6; implicit group: M = 3.36, SD = 2.76; control group: M = 2.21, SD = 1.46). In addition, a Kruskal-Wallis test revealed that the explicit group had more if-then relation knowledge than the other two groups ($\chi^2_{(2, N=51)} = 6.18$; $p < 0.05$).

Discussion

Why do differences between the experimental groups in decision quality occur only for Rule 1 and Rule 2? Rule 1 represents a pass to the wing player on the left side and Rule 2 represents a pass to the half-back player on the left. These players are the most relevant players in the tactical aim to shift the defense from the left to the right side, so that the backcourt player on the left side has more space to throw to the goal. It appears that participants almost entirely neglected the other possibilities, which was underlined by the rule-specific analysis of the questionnaire. Because Rule 3 and Rule 4 lack the information of shifting the defense from the left to the right side, it might be that these rules are not as important and, therefore, are mostly neglected by all participants. This behavior can be explained by the concept of one-reason decision-making. Participants use a one-reason heuristic when they rely on only one satisfying reason (in this example, only if the half-back player on the left side has enough space between himself and his opponent to throw to the goal) to decide what to do. One such heuristic is "Take-The-Best" (Gigerenzer, 2000), which would use the best cue (in this case the "opponent-distance cue") and ignore the rest to make the implicit judgment.

In summary, implicit learners were observed to be superior to explicit learners in decision quality, but not in explicit rule knowledge, even if more time was given to view each video clip to allow for more explicit processing. Therefore, the findings of Experiment 1 were partially replicated. These results do challenge prior findings, which show superior explicit learning in deciding in an artificial grammar task in low-complexity situations (Reber & Allen, 1978). The results of Experiments 1 and 2, that is, the superiority of the implicit learners in acquisition, are surprising. The performance was robust against forgetting (no significant changes in the four-week delayed retention test), as found in previous studies (Berry & Dienes, 1993). No interaction was found on groups and tests, indicating that the performance of the implicit group was stable over quite a long period.

Interestingly, Maxwell et al. (2000) found no differences in the performance of implicit motor and explicit motor learners in a golf-putting task in retention tests, but Reber (1989) found that implicit learning of more cognitive tasks - such as the decision task presented here - was stable for the retention test. However, this comparison has to be made carefully, because it is not clear - from the perspective of a beginner in golf putting - how complex golf putting is on different dimensions. For the beginner the motor execution may be quite complex, but choosing what option to take seems quite easy. The contradiction between Maxwell et al.'s results and the results presented here can also be explained by the difference in the cognitive proportion of the tasks and the method used. Maxwell et al. used a golf-putting task, which has a low cognitive load. In addition, they used a dual-task paradigm (tone counting) to prevent explicit processing and enhance implicit processes in the implicit treatment group. The dual task paradigm of Maxwell et al. involved a distraction from the primary task, whereas in this study an indirect attention manipulation guided people to use the environmental structure necessary to solve the problem. To check whether the indirect attention manipulation to memorize the behavior of the marked player was used, the partial-recall test during the treatment was analyzed. The results reveal a "better than chance" performance for every single implicit learner, which suggests that they paid attention to the decisions of the marked player, enabling them to remember the decisions in the partial-recall test.

Experiments 1 and 2 used situations that are of low-complexity due to a low number of options and a low number of attributes connected to them. If the complexity of the situation is enhanced and explicit learners are observed to be superior to implicit learners, it will add evidence to support the arguments of Gomez (1997) and Bennett (2000, p. 545) that explicit learning facilitates performance in high-complexity situations. Experiments 3 and 4 were designed to examine this hypothesis.

Experiment 3

Experiment 3 was designed to evaluate the effects of complexity on implicit and explicit learning in high-complexity situations. The level of complexity between Experiments 1 and 2 and Experiment 3 was manipulated in terms of both *perception* and *cognition*. Concerning perception, experts rated more complex situations, where several options were open to a marked player, using the five-point Likert scale. In addition, these situations were selected by changing the attack and defense systems. The mapping between the positions of offensive and defensive players was arranged so that every offense player was not opposed by a defense player, making direct offense-defense mappings on space-time scales more difficult. The difficulty of offense-defense mapping increased because it was no longer easy to use simple if-then rules, such as "if a player is free, allocate the ball to him."

On the cognitive side, instead of four if-then rules fitting a one-to-one mapping to four options, the participants had to learn 15 rules, where one of the five options ("then") could be reached through a number of different situations ("if"). The calculation of McCabe's (1976) complexity measure revealed a complexity-index value for Experiment 3 that was more than twice the value of the situations used in Experiments 1 and 2.

The purpose of this experiment was to observe a pattern of results that was the inverse of Experiments 1 and 2. If interaction does, indeed, take place between different learning processes and complexity, then explicit learners could now be expected to be superior.

Method

Participants

Forty-six male and female undergraduate participants between 20 and 27 years old (mean age = 24.6) from the Department of Sport and Sport Science at the University of Heidelberg, who had no prior experience in any experiments of this kind, were randomly assigned to an implicit, explicit, or control group. None had participated in Experiment 1 or 2, and all participants provided informed consent.

Description and Selection of Decision Situations

The situation in this experiment involved a "3 versus 3 attack" against a "3:2:1 defense system" in handball. The term "3 versus 3 attack" refers to the positions of the players, in which three players stay close to the defense line and three players stand in one line further back. The "3:2:1 defense system" describes the pyramid-like position of the players from the perspective of the defending goal, that is, three players stand at the defense line, two players stand further away from the defense line, and one player stands close to the playmaker of the attacking team. The playmaker on the videotape has five options for making a decision within the given situation. The 15 situations, the five options, and the number of correct and incorrect decisions were balanced for the training procedure, so that every 50 video clips presented the same number of correct and incorrect decisions for all options. The clips were selected by handball experts (junior national coaches) with the same validation procedure as in Experiments 1 and 2.

Apparatus and Material

The HVD was again modified. Now five options were possible. Two decisions were options that resulted in a throw to the goal (one-to-one break through the *left* or the *right* side from a defense player), and three decisions represented the allocation to team members (center-front [pivot] player, half-back player on the left side, half-back player on the right side). Again, each if-then rule defined which option out of the five was optimal by definition of the experts, in each situation shown in the video clips.

Procedure

The learning of 200 scenes in four weeks (50 video clips per week) was held constant, compared to Experiments 1 and 2. The main manipulation was in the video film. Fifteen rules represented the five possible decisions, which had to be learned step-by-step from easy to complex situations. Learning started with only three decisions, which could be separated on the perceptual side quite easily (mostly temporal and spatial differences between the options). For the explicit group, only two “if-conditions” mapping the same motor decision were explicitly taught each week; the implicit group needed, again, to memorize a marked player’s behavior for a partial-recall test after every 10 video clips. As in the training of handball situations in a gym, the complexity of the situation, that is, the number of options, the number of “if-conditions” to “then-actions,” and the perceptual differences, was gradually increased from week to week.

Results

The methods of analysis used in Experiments 1 and 2 were also used in this experiment.

Implicit Learning

Two 3 X 2 ANOVAs (Groups X Tests) for decision quality and decision time revealed significant differences in decision quality, $F(2,43) = 437.08$; $p < 0.01$, and decision time, $F(2,43) = 4.58$; $p < 0.01$. Post hoc analyses supported the expected lower performance of the control group, compared to the treatment groups for decision quality and decision time ($p < .05$). The explicit group ($M = 33.80\%$, $SD = 3.87$) was superior ($p < .05$) to the implicit group ($M = 29.40\%$, $SD = 2.88$) in number of correct decisions (Figure 2). Again, the performance of the implicit and explicit groups was above chance level (20% by five equally distributed options).

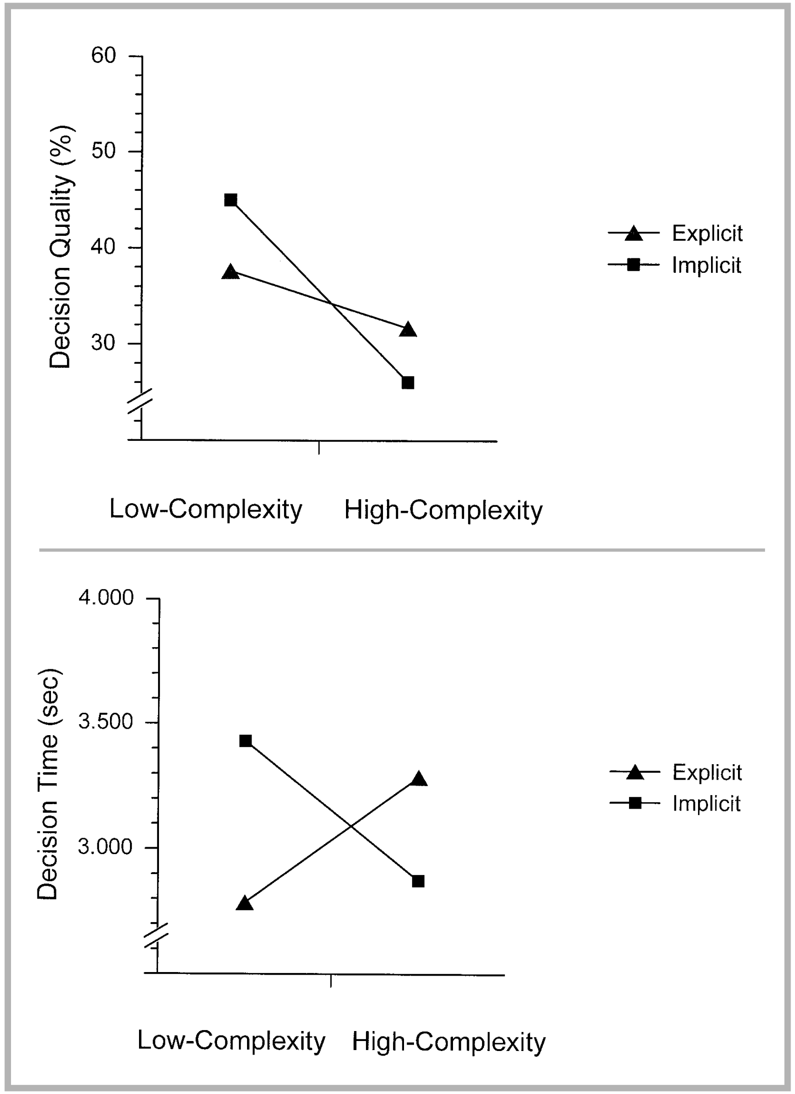

Figure 2. Interaction of implicit and explicit learning processes and complexity in Experiments 1 and 3 (left: decision quality, right: decision time in milliseconds. Low complexity is Experiment 1 and high complexity is Experiment 3).

There were no differences between the implicit and the explicit groups for decision time. This result pattern remained stable in the retention test four weeks later. Again, no interaction between groups and tests was found.

Explicit Knowledge

The analysis of knowledge revealed no reportable differences in quantitative ($p > .05$) or qualitative ($p > .05$) terms between the explicit and the implicit group. The lack of a difference can be explained by the low scores of both groups, which did not go beyond a mean score of two points in the scale of quantitative knowledge (a maximum of 9 points). The quite complex task of mapping 15 if-then relations to the presented video clips appears difficult to verbalize. In summary, the implicit groups could not verbalize the if-then rule structure of the video clips very well, but they performed over chance level in the task.

Discussion

The findings of Experiment 3 illustrate the concept of interactions of implicit and explicit processes with complexity and support the argument that in high-complexity situations explicit learning enhances coping with the demands of the task. However, there were no significant differences in explicit knowledge, so it cannot be ruled out that the explicit learning group also learned, in part, implicitly. The possible parallel acquisition of implicit and explicit learning will be discussed in the general discussion section. In low-complexity situations, on the other hand, explicit learning decreases the percentage of correct decisions. The explanation for the different effects of implicit and explicit learning on decision making in situations of different complexity may be that in low-complexity situations the implicit judgment of stimuli leads to sufficient decisions. If explicitly learned if-then rules are brought into play, these interfere with the implicit judgments and result in more incorrect decisions (Reber & Kotovsky, 1997). In high-complexity situations, the simple mechanism of implicit judgment of stimuli cannot be as helpful. One reason for this may be that too many stimuli are visible, and too many stimuli result in the same decision. Therefore, explicit learning that enhances a selection of necessary stimuli, mapping these to the judgments about which option is the best, results in more correct decisions. In real sports environments, athletes are guided to the “information-rich areas” (Magill, 1998) in high-complexity situations by explicit instructions. For the novice player, this guidance can support the effects of the learning process.

The generalization of these findings is limited for two reasons. First, effects in the laboratory were elicited by self-produced video scenes, selected by an expert as being most typical to real situations. However, such video scenes are only an approximation to real situations, and presenting real competition situations may result in different effects. Second, in handball and basketball, the physical distance of players greatly influences the decisions. For example, within the stimulus material there may be some decisions influenced just by the different sizes of players or by minor differences between the options due to the spatial distance of opposing players. To overcome these limitations, in Experiment 4, volleyball situations were chosen from footage of female World League Championship competitions to ensure ecological validity in an open sport, where tactical decisions of an individual player (e.g., the setter) are less influenced by the physical appearance of the opponents or the opponents’ movements.

Experiment 4

The purpose of Experiment 4 was to replicate the results of Experiment 3 - that explicit learners are superior in decision quality, compared to implicit learners, in high-complexity situations. This experiment was conducted using a volleyball situation to extend the results to a different type of sports. The HVD used real video scenes from high-level competitions. Participants were required to view the behavior of a setter (playmaker in volleyball) in a defense situation that could best be described in 12 if-then rules (see Raab & Stˆhrer, 1997, for details).

Method

Participants

Forty-five female and male undergraduate students between 21 and 28 years old (mean age = 24.8) from the Department of Sport and Sport Science at the University of Heidelberg were randomly assigned to the implicit, explicit, or control group. None had participated in any of the three preceding experiments, and all participants provided informed consent.

Description and Selection of Decision Situations

Volleyball experts defined rules for a situation in which a setter in volleyball (playmaker) had to set, for the defense of her team, to five possible positions. Twelve rules were involved to define in which situation a setter had to play one of the five sets. The five options for the playmaker were the three players in the front row (the setter was a back-row setter, which meant that she could run from the back row to the front row to increase the number of players who are allowed to spike within the attack zone) and the two players in the back row, who spike from the back row.

Apparatus and Material

The HVD for volleyball was built to enhance the complexity of the situation. The task situation was designed to map, as much as possible, the situation a setter has in the competition situation. Therefore, the participants’ task was to watch the video clip in a defense position and run to a position from where they would set the ball after their teammates defended a ball from the opponents (see Figure 3). This was done by moving from a start mat to one of four possible positions in the field represented by mats on the floor. From there, participants were asked to set the ball to three front-row players and two backcourt players. Participants had to throw the ball at the ceiling mats that represented the trajectory the ball should take to reach one of the five players.

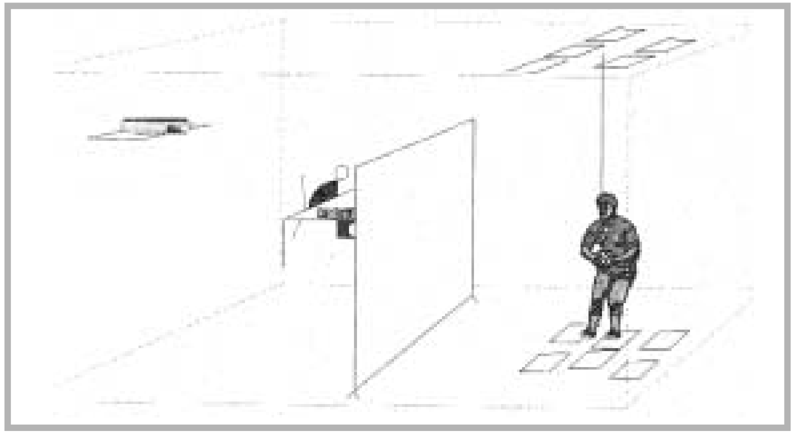

Figure 3. HVD for volleyball decisions. The participant stands in front of the video projection and has to decide to whom to set by implementing a real set with the ball, passing it to one of the five options marked on the ceiling.

Procedure

The practice period was again four weeks. Participants took part in four sessions of 50 video clips (one session per week). Perceptual and motor complexity of the situations was gradually increased over the sessions from week to week. Again, the practice period was constant in respect to the number of trial video clips and the distribution of video clips over the four weeks. For purposes of comparison to the prior experiments, the amount of training in the more complex situation was not increased. Since, in general, more complex tasks require longer training periods than easier tasks, smaller differences are expected between control and treatment groups when the amount of learning is kept constant. The practice procedure was adapted from Experiment 3.

Results

The same outlier procedure and the transformation of explicit knowledge as in the previous experiments were used. Only the decisions in which the participant hit the desired mats on the ceiling (less than 2% missing data) were included.

Two 3 X 2 ANOVAs (Groups X Tests) for decision quality and decision time were calculated. There were differences between the groups in terms of decision quality ($F(2, 42) = 6.39$; $p < 0.01$), but not in terms of decision time ($F(2, 42) = 1.60$; $p > 0.05$). Again, the explicit group ($M = 31.72$, $SD = 7.5$) was significant superior to the implicit group ($M = 26.09$, $SD = 8.72$) in terms of decision quality (Scheffé, $p < .05$), but not for decision time (Figure 4). Both groups were superior ($p < .05$) to the control group in post hoc comparisons (Scheffé) for decision quality. Both the implicit and the explicit groups performed above chance (20% by five equally distributed options).

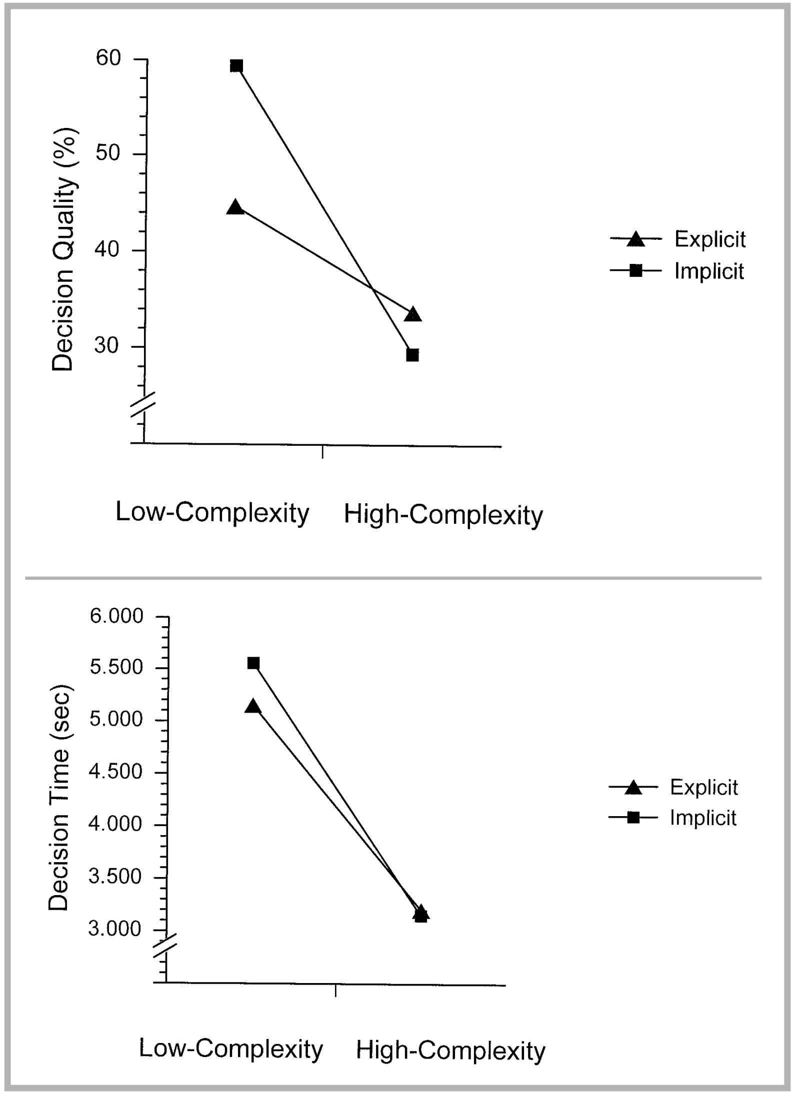

Figure 4. Interaction of implicit and explicit learning processes and complexity of Experiments 2 and 4 (left: decision quality, right: decision time in milliseconds). Low complexity is Experiment 2 and high complexity is Experiment 4).

In the retention test, four weeks later, the explicit group was better than the implicit group by approximately the same margin. No interaction between groups and tests could be found, as reported in the other experiments.

Explicit Knowledge

The explicit group was found to possess more quantitative knowledge than the implicit group ($F_{(2, 27)} = 3.96$; $p < 0.05$), but no significant differences are reportable for qualitative results. The level of the explicit knowledge of the implicit group was low ($M = 3.32$, $SD = 1.36$), indicating the implicit nature of the decision-making in the test.

Discussion

In Experiment 4, the explicit learning group performed better in the tactical decision task, in terms of decision quality, than the implicit group in the post test and the retention test. This result pattern fits the result pattern of Experiment 3 and supports the argument that decision making in high-complexity situations requires some explicit learning. The learning of explicit if-then rules may enforce stimuli judgments that map the decisions appropriately to the variations of the situation at hand (Seger, 1997).

General Discussion

This article focuses on the interaction between implicit and explicit learning, and complexity in decision making in sports. In the sports psychology literature this interaction has been neglected. Two situations of different complexity were used to show that the advantages of the implicit and explicit learning of tactical decisions in sports depend on the complexity of the situation. The literature provides no clear support for one main direction of an interaction of learning and complexity: In previous research, implicit learning in decision making has been found to be superior in low-complexity situations and explicit learning superior in high-complexity situations, and vice versa. For instance, Reber and Allen (1978) found that in artificial grammar experiments implicit learning is superior in high-complexity situations, and Gomez (1997) found that explicit learners are superior in high-complexity situations.

To obtain an overall pattern of results, two 3 X 2 X 2 three-factor ANOVAs (Groups X Tests X Complexity) were calculated for decision quality and decision time. The data from Experiments 1 and 2 and from Experiments 3 and 4 were combined for this analysis. This could be done because no experimental main effect was found in a prior analysis of four factors, including the experiments as the fourth factor. For both decision time, $F(11, 184) = 5.71$; $p < 0.01$, and decision quality, $F(11, 184) = 3.76$; $p < 0.05$, the interaction between complexity and groups was found to be significant. Implicit learners are superior to explicit learners in low-complexity situations, and explicit learners are superior in high-complexity situations. This effect is in the middle range ($eta^2 = 0.05$), and is derived from the complexity effect ($eta^2 = 0.31$) and the group effect ($eta^2 = 0.06$). However, as can be seen by the effect values, the complexity effect size is high, whereas the group effect size is of middle range. To derive a more precise effect size, by comparing only the means of the implicit and explicit group, Cohen's *d* was used for a group complexity and interaction measure showing that the interaction is in the middle range (mean d = .47), again with the very high score for complexity ($d = 1.5$). These results are consistent with those of Dulany et al. (1984) and Gomez (1997) showing the same interaction of implicit and explicit learning and complexity in artificial grammar tasks. The results are inconsistent with those of Dienes et al. (1991), Reber and Allen (1978), and Reber et al. (1980) concerning the direction of the interaction, again, in artificial grammar tasks. At this point, it can be claimed that cognitive explicit learning is necessary in sports-specific decision making when perceptual and cognitive demands are high. When the two processes conflict (Reber & Kotovsky, 1997), explicit information interferes with implicit processes so that only implicit learning can result in better decision making. No such interference condition was learned in this study and therefore it needs to be directly investigated (Raab, 2000b). In high-complexity situations, however, this implicit process is no longer sufficiently powerful and, therefore, explicit processes lead to better decisions.

It can be argued that results found in artificial grammar tasks, or other paradigms used in sports, differ from this work in three crucial aspects. First, the information given (e.g., space-time relevant information vs. artificial letter sequences), the task (e.g., dynamic decisions derived from four or five alternatives vs. "yes-or-no" grammar answers), and the situation (e.g., time pressure vs. no time pressure) differ significantly. These aspects, together or any one of them separately, may influence the different interactions; these must be tested to provide further evidence of what task-specific differences caused the different interactions.

Second, it is argued that implicit and explicit processes interfere with one another, and that both influence decision making in sports. Implicit learners accepted the cover story, as the debriefing showed, but some aspects of the if-then rules could be verbalized in the follow-up questionnaire. In three out of four experiments, explicit learners, as expected, verbalized significantly more knowledge. It is also plausible that explicit learners may use implicit processes in decision making to some degree. So no process-pure approach, such as only implicit learning or only explicit learning, is assumed here (see Raab, 2000b, for different types of interactions between implicit and explicit processes).

Third, the main research in sports on implicit learning has concentrated on motor tasks to show that in retention, implicit learners perform equally well. It is not surprising that implicit learning is, in the long run, an effective process for motor performance, because the task itself requires only producing the movement, and explicit knowledge is not necessary. This argument, however, was not extended to more cognitive tasks, such as to whom to pass the ball next. The extension of implicit and explicit processes to more cognitive tasks, such as tactical decision making in sports, has not been investigated before, but the unquestioned assumption has been stated: that explicit processes result in better decisions, supported by cognitive dual-process theories that also argue for a priority of the explicit system (Evans, 1989). This research investigated this assumption and showed that no system obtains a priority per se, but rather, that the two processes are adaptive to environmental changes. Note that these results have no direct implications for the implicit motor learning research in sports. However, the multi-task, multi-experiment procedure can be adopted in implicit motor research to explore the boundaries of the "less-is-more" effect in movement execution. It would also be interesting to see whether the benefits of implicit motor learning would hold if simultaneous demands on the movement selection and on the selection of parameters in the same movement were made.

The complexity of the situation, in many respects, serves as a crucial factor in understanding the advantage of having two adaptive systems. The present research does not clarify how much complexity is required to observe the switches of superior performance from implicit to explicit learning. In addition, it is unknown if this result can be generalized over the games and situations manipulated in the four experiments. However, a formalized measure of complexity was presented that may lead to further investigations and tests to determine if these results hold in other domains as well. This research manipulated the complexity of the environment by the amount and connectivity of information given. The amount of information given, or selected from the environment, can be used in an implicit and an explicit way.

Beek (2000) encouraged researchers to reach a theory of implicit learning in the perceptual-motor domain. This attempt is applied to the implicit and explicit judgment of stimuli to make decisions in sports situations. The proposed simple view is that cognition is best understood by looking at its environment (Simon, 1956). The bounded rationality approach looks at the interaction of cognitive strategies and the structure of the environment. This framework can be applied to the domain of decision making in sports to develop a better understanding about the boundedness of cognitive and sensorimotor processes (Raab, & Gigerenzer, in press). To be precise, any research investigating implicit and explicit processes in the sports domain has to consider the environment: "Thus the normative question of whether a cognitive mechanism, or its absence, is good or bad, rational or irrational, is one that needs to be answered relative to an environment" (Gigerenzer & Fiedler, manuscript in preparation).

From this research, only very general applications can be drawn to training methods of decision making in sports. Bennett (2000, p. 546) concluded that the benefits of implicit learning, transferred to the sports application, should be treated with some caution before more moderating factors are known. In the case of tactical decisions in ball-game situations, the current research indicates that training in decision making should be oriented toward incidental methods in low-complexity situations, whereas intentional methods should be used for high-complexity situations. The research presented here is a first step toward building a taxonomy of the structure of the environment and the structure of human processes that goes beyond the less-is-better or more-is-better ideologies presented previously.

References

Bard, C., Fleury, M., & Goulet, C. (1994). Relationship between perceptual strategies and response adequacy in sport situations. *International Journal of Sport Psychology, 25*, 266-281.

Beek, P. J. (2000). Toward a theory of implicit learning in the perceptual-motor domain. *International Journal of Sport Psychology, 31*, 547-554.

Bennett, S. J. (2000). Implicit learning should it be used in practice? *International Journal of Sport Psychology, 31*, 542-546.

Berry, D., & Cock, J. (1998). *Implicit learning of invariant features?* Thousand Oaks: Sage.

Berry, D. C., & Dienes, Z. (1993). *Implicit learning: Theoretical and empirical issues.* Hove, UK: Erlbaum.

Boradbent, D. E., Fitzgerald, P., & Broadbent, M. H. (1988). Implicit and explicit knowledge in the control of complex systems. *British Journal of Psychology, 77*, 33-50.

Buchner, A., Funke, J., & Berry, D. (1995). Negative correlations between, and evaluations of some process dissociation measurement models. *Quarterly Journal of Experimental Psychology, 48,* 166-187.

Chaiken, S., & Trope, Y. (Eds.). (1999). *Dual-process theories in social psychology.* New York: Guilford Press.

DeShon, R. P., & Alexander, R. A. (1996). Goal setting effects on implicit and explicit learning of complex tasks. *Organizational Behavior and Human Decision Processes, 65,* 18-36.

Dienes, Z., Broadbent, D., & Berry, D. (1991). Implicit and explicit knowledge bases in artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 17,* 875-887.

Dulany, D. E., Carlson, R. A., & Dewey, G. I. (1984). A case of syntactical learning and judgment: How conscious and how abstract? *Journal of Experimental Psychology: General, 113*, 541-555.

Engelkamp, J. (1998). *Memory for actions.* Hove, UK: Erlbaum.

Evans, J. St. B. T. (1989). *Bias in human reasoning.* Hillsdale, NJ: Erlbaum.

Farrow, D., & Abernethy, B. (2002). Can anticipatory skills be learned through implicit video-based perceptual training? *Journal of Sports Sciences, 20,* 474-485.

French, K. E., & Thomas, J. R. (1987). The relation of knowledge development to children's basketball performance. *Journal of Sport Psychology, 9,* 15-32.

Frensch, P. A. (1998). One concept, multiple meanings: On how to define the concept of implicit learning. In M. A. Stadler & P. A. Frensch (Eds.), *Handbook of implicit learning* (pp. 47-104). Thousand Oaks: Sage.

Gigerenzer, G. (2000). *Adaptive Thinking: Rationality in the real world.* Oxford: Oxford Press.

Gigerenzer, G., & Fiedler, K. (in prep.). When research neglects ecological structure. In P. M. Todd, G. Gigerenzer & The ABC Research Group. (Eds.), *Ecological rationality.*

Gigerenzer, G., & Todd, P. M. (1999). Fast and frugal heuristics: The adaptive toolbox. In G. Gigerenzer, P. M. Todd, & The ABC Research Group. *Simple heuristics that make us smart* (pp. 3-36). Oxford: University Press.

Gigerenzer, G., Todd, P. M. & The ABC Research Group. (Eds.). (1999). *Simple heuristics that make us smart.* Oxford: University Press.

Goldstein, D. G., & Gigerenzer, G. (2002). Models of ecological rationality: The recognition heuristic. *Psychological Review, 109,* 75-90.

Gomez, R. L. (1997). Transfer and complexity in artificial grammar learning. *Cognitive Psychology, 33,* 154-207.

Helsen, W., & Powells, J. M. (1993). The relationship between expertise and visual information processing in sport. In J. L. Starkes & F. Allard (Eds.), *Cognitive issues in motor expertise* (pp. 109-134). Amsterdam: Elsevier Science.

Johnstone, T., & Shanks, D. R. (2001). Abstractionist and processing accounts of implicit learning. *Cognitive Psychology, 42*, 61-112.

Kirsner, K., & Speelman, C. (1998). Introduction and overview. In K. Kirsner, C. Speelman, M. Mayberg, A. O'Brien-Malone, M. Anderson, & C. MacLeod (Eds.), *Implicit and explicit mental processes* (pp. 3-12). Mahwah, NJ: Erlbaum.

Liao, C. M., & Masters, R. S. W. (2001). Analogy learning: A means to implicit motor learning. *Journal of Sport Sciences, 19*, 307-319.

Magill, R. A. (1998). Knowledge is more than we can talk about: Implicit learning in motor skill acquisition. *Research Quarterly for Exercise and Sport, 69,* 221-256.

Masters, R. S. W. (1992). Knowledge, knowers and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83,* 343-358.

Masters, R. S. W. (2000). Theoretical aspects of implicit learning in sports. *International Journal of Sport Psychology, 31,* 530-541.

Masters, R. S. W., Law, J., & Maxwell, J. (2002). Implicit and explicit learning in interceptive actions. In K. Davids, G. Savelsbergh, & J. van der Kamp (Eds.), *Interceptive actions in sport: Information and movement* (pp. 126-143). London: Routledge.

Mathews, R. C., Buss, R. R., Stanley, W. B., Blanchard-Fields, F., Cho, J. R., & Druhan, B. (1989). Role of implicit and explicit processes in learning from examples: A synergistic effect. *Journal of Experimental Psychology: Learning, Memory and Cognition, 5*, 1083-1100.

Maxwell, J. P., Masters, R. S. W., & Evers, F. F. (2000). From novice to no know-how: A longitudinal study of implicit learning. *Journal of Sport Sciences, 18,* 111-120.

McCabe, T. J. (1976). A complexity measure. *IEEE Transactions on Software Engineering, 2,* 308-320.

McMorris, T. (1998). Teaching games for understanding: Its contribution to the knowledge of skill acquisition from a motor learning perspective. *European Journal of Physical Education, 3,* 65-74.

McPherson, S. L., & Thomas, J. R. (1989). Relation of knowledge and performance in boys' tennis: Age and expertise. *Journal of Experimental Child Psychology, 48,* 190-211.

O'Brien-Malone, A., & Maybery, M. (1998). Implicit learning. In K. Kirsner, C. Speelman, M. Mayberg, A. O'Brien-Malone, M. Anderson, & C. MacLeod (Eds.), *Implicit and explicit mental processes* (pp. 37-56). Mahwah, NJ: Erlbaum.

Perrig, W. J. (1996). *Implizites Lernen* [Implicit learning]. In J. Hoffmann & W. Kintsch (Eds.), Lernen [Learning] (pp. 203-234). Göttingen, Germany: Hogrefe.

Raab, M. (2002a). T-ECHO: Model of decision making to explain behaviour in experiments and simulations under time pressure. *Psychology of Sport and Exercise, 3,* 151-171.

Raab, M. (2000b). Wechselwirkungen taktischer Entscheidungsprozesse [Interactions between tactical decision-making processes]. *Psychologie und Sport, 9,* 145-158.

Raab, M., & Gigerenzer, G. (in press). Intelligence as smart heuristics. In R. J. Sternberg, J. Davidson & J. Pretz (Eds.), *Cognition and Intelligence.*

Raab, M., & Stöhrer, M. (1997). Zuspiel nach erfolgreicher Abwehr: Eine Situationsanalyse. [Pass after successful defense: An analysis of a situation]. In F. Dannenmann (Ed.), *Volleyball '96- Facetten des Spiels. 22. Symposium des Deutschen Volleyballverbandes* [Volleyball '96 - Facets of the game. 22. Congress of the German Volleyball Association] (p. 31-42). Hamburg, Germany: Czwalina.

Rathus, J. H., Reber, A. S., Manza, L., & Kushner, M. (1994). Implicit and explicit learning: Differential effects of affective states. *Perceptual and Motor Skills, 79,* 163-184.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 6,* 855-863.

Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General, 118,* 219-235.

Reber, A. S., & Allen, R. (1978). Analogy and abstraction strategies in synthetic grammar learning: A functionalist interpretation. *Cognition, 6,* 189-221.

Reber, A. S., Kassin, S. M., Lewis, S., & Cantor, G. (1980). On the relationship between implicit and explicit modes in the learning of a complex rule structure. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 492-502.

Reber, P. J., & Kotovsky, K. (1997). Implicit learning in problem solving: The role of working memory capacity. *Journal of Experimental Psychology: General, 126,* 178-203.

Reber, A. S., & Lewis, S. (1977). Toward a theory of implicit learning: The analysis of form and structure of a body of tacit knowledge. *Cognition, 5,* 333-361.

Ripoll, H. (1991). The understanding-acting process in sport: The relationship between the semantic and the sensorimotor visual function. *International Journal of Sport Psychology, 22,* 221-243.

Rossetti, Y., & Revonsuo, A. (Eds.). (2000). *Beyond dissociation: Interaction between dissociated implicit and explicit processing.* Amsterdam, The Netherlands: John Benjamin Publishing Co.

Seger, C. A. (1994). Implicit Learning. *Psychological Bulletin, 115,* 163-196.

Seger, C. A. (1997). Two forms of sequential implicit learning. *Consciousness and Cognition, 6,* 108-131.

Shea, C., Wulf, G., Whitacre, C. A., & Park, J. H. (2001). Surfing the implicit wave. *Quarterly Journal of Experimental Psychology, 54A*, 841-862.

Siemann, M., & Gebhardt, R. P. (1996). Einfluss der Instruktion und Aufgabenkomplexität auf transitive Entscheidungen [Effects of instructions und task complexity in transitive decisions]. *Zeitschrift für Experimentelle Psychologie, 2,* 435-460.

Simon, H. A. (1956). Rational choice and the structure of environments. *Psychological Review, 63,* 129-138.

Singer, N., Lidor, R., & Cauraugh, J. (1993). To be aware or not to be aware? *Sport Psychologist, 43,* 19-30.

Sloman, S. A. (1996). The empirical case for two systems of reasoning. *Psychological Bulletin, 119,* 3-22.

Squire, L. R., & Frambach, M. (1990). Cognitive skill learning in amnesia. *Psychobiology, 18,* 109-117.

Stadler, M. A., & Frensch, P. A. (Eds.). (1998). *Handbook of implicit learning.* Thousand Oaks: Sage.

Streufert, S., & Castore, C. H. (1971). Information search and the effects of failure: A test of complexity theory. *Journal of Experimental Social Psychology, 7,* 125-143.

Sun, R., Merrill, E., & Peterson, T. (2001). From implicit skill to explicit knowledge: A bottom-up model of skill learning. *Cognitive Science, 25,* 203-244.

Thorndike, E. L., & Rock, R. T., Jr. (1934). Learning without awareness of what is being learned or intend to learn. *Journal of Experimental Psychology, 17,* 1-19.

Vickers, J. N., Livingston, L. F., Umeris-Bohnert, S., & Holden, D. (1999). Decision training: The effects of complex instruction, variable practice and reduced delayed feedback on the acquisition and transfer of a motor skill. *Journal of Sports Sciences, 17,* 357-367.

Wickens, C. D. (1992). *Engineering psychology and human Performance.* (2nd edition), Illinois: Harper Collins.

Williams, A. M., Davids, K., Burwitz, L., & Williams, J. G. (1993). Cognitive knowledge and soccer performance. *Perceptual and Motor Skills, 76,* 579-593.

Wood, R. E. (1986). Task complexity: Definition of the construct. *Organizational Behavior and Human Decision Processes, 37,* 60-82.

Wulf, G., & Schmidt, R. A. (1997). Variability of practice and implicit motor learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 7,* 11-18.

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