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Improving the ‘how’ and ‘what’ decisions of elite table tennis players

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Abstract

Training methods in sport usually focus on improving either technical *or* tactical aspects of performance, ignoring the fact that successful performance requires the athlete to simultaneously decide what movement to perform and how it should be executed. Young elite table tennis players were trained, in a first phase, to improve their forehand and backhand movements and, in a second phase, to make a tactical switch between forehand and backhand movements. Half of the players took part in behavioral training focusing on how to perform the required movements, whereas half received additional video feedback about their technical and tactical performance (decision training). The results indicate that improvements of how decisions (techniques) and what decisions (tactics) can occur as a consequence of combining technical and tactical training. These results were stable in delayed post-test analyses of competitive matches. It was concluded that a combination of both technical and tactical training is beneficial to elite table tennis performers, particularly during early seasonal training programs.

PsycINFO classification: 2330; 2340; 2343

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1. Introduction

Deciding what movement to perform and how to execute it are important components of elite performance in sport. In table tennis and other fast ball games the brevity of the response window, dictated by the speed of the ball, forces performers to use advanced cues to decide ‘what’ response is required and ‘how’ that movement should be carried out (Abernethy, 1991). Thus, issues concerning the training of appropriate decisions about what to do (tactics) and how to do it (techniques) need to be addressed (Thorpe & Bunker, 1989). The relevance of both forms of decision for effective performance is widely acknowledged in sport - tactical and technical training methods are common in all sports. However, the effects of combining both types of training are poorly understood. The following experiment contrasts a combination of decision (‘what’) and behavioral (‘how’) training with behavioral training only. Performance is assessed by analysis of kinematic parameters and performance accuracy relative to what (transitions between forehand and backhand in table tennis) and how decisions (the movement relative to a norm) in movement sequences.

The novelty of the approach adopted in the present study is to combine how and what decisions that are usually treated separately in order to reduce the complexity of the learning situation. The separation of decision and behavioral training can be found in most research involving motor learning in sport. For example, in the implicit/explicit learning literature, Masters (2000) cited a number of studies that have demonstrated benefits of implicit motor learning. However, the tasks used in these experiments typically require the acquisition of a specific motor response to a single stimulus (e.g. putting towards a hole); thus, decision making is not involved. Even in research using variable practice, the decision to use one technique/response rather than another is often redundant due to constrained task demands (e.g. Lee, Magill, & Weeks, 1985).

1.1. Decision training

An exception to the reported dissociation between learning ‘how’ to perform movements and learning ‘what’ movements to select are approaches that compare behavioral training with decision training (Vickers, 2003). Vickers (2003) defines traditional behavioral training as skill-oriented, where the same skill is repeated over and over again. Movements are broken down into constituent chunks and built up slowly into the whole movement, progressing from simple to complex. Tactical information is regarded as complex and is usually supplied once movement production has been mastered. The motivation for using this technique comes from the notion that skills progress serially from declarative to procedural (Anderson, 1983; Fitts & Posner, 1967; Schneider & Schiffrin, 1977). The processing of declarative knowledge depends on limited attention resources, whereas procedural responses are less attention demanding. Actions are gradually proceduralized in order to free up attention resources that can then be devoted to more complex variations of the proceduralized skill. However, there is an accumulating literature that supports parallel development of declarative and procedural knowledge (e.g. Gentile, 1998; Maxwell, Masters, & Eves, 2003) and hints that a combination of decision and behavioral training may be beneficial.

Vickers’ (2003) “decision training” approach (actually a combination of ‘decision’ and ‘behavioral’ training; however to make the distinction between behavioral and decision training more transparent Vickers’ labels are retained throughout this manuscript) was based on the idea that skills should be learned as they are to be performed. Vickers integrated the existing motor learning literature and emphasized the training of cognitive aspects involved in decisions rather than only movement execution. In short, this approach proposes that skills should be acquired as a gestalt whole that does not separate declarative from procedural, or technical from tactical, because performance requires efficient integration of all sources of information/knowledge. Decision training was designed to include variable practice, delayed and reduced feedback, and tactically oriented instructions (Vickers, 2000; Vickers, Reeves, Chambers, & Martell, 2004). Vickers (2003) summarized findings from both behavioral and decision training in different sports, concluding that behavioral training leads to greater improvements in skill performance during acquisition, but decision training results in better performance during retention and transfer trials, implying that this method is more effective for the rapidly changing environment experienced by most athletes when performing in competition.

Vickers, Livingston, Umeris-Bohnert, and Holden (1999) reported that decision training seemed to be particularly useful for intermediate and advanced performers, whereas behavioral training was more efficient for novices. However, the effectiveness of combining both behavioral and decision strategies into a single training regime has not been assessed. It is possible that behavioral training exerts its influence primarily on ‘how’ to perform an action, whereas decision training benefits ‘what’ movement should be performed. The current experiment analyses these possibilities using young, elite table tennis players.

1.2. ‘What’ and ‘how’ decisions in table tennis

Table tennis is a prototypical sport in which players have to decide what movement to perform and how to carry out the movement within a very short time. Roth (1989) showed, in laboratory based pre-cueing experiments, that to make corrections to stroke parameters in table tennis (‘how’ decisions) participants require a response window of at least 399 ms prior to execution. ‘What’ decisions, however, require 556 ms, based on movement durations of about 370 ms (from start of swing to bat-ball contact). These time windows indicate that the selection and execution of sequential table tennis movements are performed, to some degree, in parallel.

A number of factors, such as movement efficiency, task complexity, uncertainty, and speed, influence the effectiveness of movements. To improve movement efficiency, a number of different acquisition techniques have been devised. For instance, Liao and Masters (2001;

Experiment 1) reported that analogy learning, in which a performer is provided with a biomechanical metaphor of how a movement should be executed, rather than traditional explicit instruction methods, results in performance that is both robust under psychological stress and secondary task loading. Liao, and Masters (2001) argued that these characteristics, coupled with the verbally inaccessible nature of the movement production, are indicative of the involvement of implicit processes that are unlikely to place a large load on working memory resources. Reducing working memory demands during movement execution frees attention for performance of other task parameters (e.g., response selection).

The complexity of tasks can have an acute effect on both execution and selection of responses (e.g., Fitts, & Posner, 1967). Reducing or increasing the amount of time between ‘what’ and ‘how’ decisions by manipulating ball speed or altering the size or weight of the ball (Xiaopeng, 1998) can have a major impact on performance.

Increasing the number of possible stimuli and responses can also affect shot quality by introducing uncertainty. Ripoll (1989), for example, found that for ‘uncertain’ situations (e.g., match conditions) the movement preparation phase was increased compared to ‘certain’ situations (e.g., training drills), whereas the movement’s execution phase remained constant. Players in uncertain conditions need a larger time window for visual encoding of cues such that shot direction can be anticipated.

The temporal and spatial characteristics of ball flight also affect response selection and execution. Sorensen, Ingvaldsen, and Whiting (2001) showed that ball location serves as a parameter for the selection of the stroke, either forehand or backhand, in conditions with known (forehand/backhand) and unknown alternation (random sequence). The percentage of forehand and backhand strokes was systematically correlated to the spatial position of the ball relative to the edge of the table, replicating prior findings (Bootsma, Houbiers, Whiting, & van Wieringen, 1991). Bootsma et al. showed that use of dynamic information about ball approach resulted in a greater number of target hits relative to conditions when this information was not available because the ball was delivered from a constant point.

Finally, the construction of the learning environment influences later task performance and transfer. For instance, Zeng (1990) produced practical evidence that random training of movement parameters and movement programs outperforms non-random training in subsequent movement accuracy. Similarly, Szymanski (1997) found in a laboratory experiment that post-test performance (accuracy) was superior for groups that learnt to change between different targets and different movements compared to a uniform group (both same target, same movement), supporting the idea that decision training leads to superior performance.

1.3. Predictions

1.3.1. Group differences in learning

In the present experiment, it was predicted that a combined behavioral and decision training approach (hereafter referred to as 'decision training') would result in performance (post-training) that is better than a solely behavioral training approach, both in respect of movement outputs ('how' decisions) and transitions between movements ('what' decisions). In addition, this superiority was expected in both short- (acquisition) and long-term (retention) learning, disagreeing with Vickers (2003) who showed better performance for behavioral training in the short–term and decision training only in the long-term.

The rationale for assuming superiority of decision training in *acquisition* and *retention* is based on rapid improvements in movement production (Daugs, Blischke, Marshall, & Müller, 1990) and movement selection (Bert, & Raab, 2003) seen in previous studies that use video feedback as part of the protocol. For instance, Bert, and Raab (2003) showed that presenting table tennis players with video feedback about movement selection rules is not cognitively demanding and can produce learning within four weeks. One reason why Vickers

(2003) argued for larger improvements of decision training in retention only, is the high cognitive effort when decision training is applied in an explicit manner (verbal instruction). Decision training given by video may be more implicit in nature, thereby reducing cognitive load consistent with the observations of Bert and Raab (2003).

1.3.2. Effects of decision training on 'how' decisions

It is currently unclear how decision training influences the performance of a skill at the biomechanical/kinematic level or whether and how learners adjust their movements by video information. Production of videos, to provide performers decision training with feedback, allows concurrent collection of three-dimensional motion analysis data that can be used to investigate the effects of training. It also allows an analysis of the effects of ball speed, uncertainty, and frequency of transitions on movement selection and execution in a controlled environment. It was predicted that increased movement variability and reduced accuracy would be present as a consequence of increased ball speed (Xiaopeng, 1998). Performance (target accuracy) increases were expected when more information about the next potential move is available to the performer (i.e., increased certainty; Roth, 1989). In addition, in uncertain (match-like) situations (Ripoll, 1989), with increased number of transitions between forehand and backhand, the trajectory length of the movement preparation phase was expected to shorten as a consequence of decision training. The effect of long term training on these and other movement parameters is currently unknown; therefore, the end product of decision training on these parameters was investigated.

1.3.3. Effects of decision training on 'what' decisions

Increasing the number of transitions between backhand and forehand should reduce the effectiveness of performance, both in terms of execution and outcome (i.e., hitting the target zone) and selecting the correct response. Previously, movement performance has been analyzed during single trials (e.g., Ripoll, 1989). The current data allow analysis of movement execution and outcome during trial sequences. The position of the transition within the sequence of movements should not influence performance; however, performance should be better in conditions in which players are aware of the upcoming sequence as opposed to sequences in which players do not know the next moves (certain versus uncertain situations). This analysis also allows extension of Bootsma, and van Wieringen's (1990) findings to different kinds of sequences and speeds.

2. Method

2.1. Participants

Twenty young elite table tennis players (mean age 11.4 years, SD 1.6 years; mean training experience of 4.7 years; 11 females and 9 males) were recruited from the German Olympic Training Centre (National team C candidates) to participate in this study. National level coaches (n = 2) provided player evaluations and training regimes; Olympic Centre training coaches (n = 4) supervised daily training sessions. Players were assigned quasi randomly to one of two groups (Behavior Group or Decision Group). Pairs (ordered by national coaches) played a standard training game of three sets within the official rules of the international table tennis federation and coaches evaluated their individual techniques. Based on the coaches' evaluations, individuals were assigned to either the Behavior or Decision Group so that the performance level of each group was equivalent. The national coaches, who made subsequent player evaluations, were blind to which player was assigned to which group. All participants provided informed consent before participating in the study. The experiment has been carried out according to the ethical guidelines of the University of Heidelberg and approval was obtained by the ethical committee.

2.2. Design

Player performance was assessed over a period totaling six months, via (i) subjective ratings based on observation of players and (ii) objective measurements obtained from laboratory based performance data. Therefore, two test designs are reported. The observational data were collected pre-intervention, mid-intervention, post-intervention, and delayed post-intervention. The same measurement criteria were used for all four observation periods. A Group by Test (2 x 4) design with repeated measures on the latter factor was employed to analyze these data. The laboratory based performance data were collected at Pre-test and Post-test for the *Decision Group only*. A within subject design was employed to differentiate movement execution and selection performance. The main aim of this analysis was to assess the effect of training on the Decision Group's ability to execute and select movements in response to controlled experimental conditions that manipulated ball speed, uncertainty, and transition frequency. Unfortunately, time and resource restrictions did not allow corresponding data collection for the Behavior Group. Intervention, in both cases, involved nine weeks of structured training based on schedules devised as a result of pilot testing and consultation with two National level table tennis coaches.

2.3. Procedure

The overall temporal ordering of the procedure is illustrated in Figure 1. The groups differed in only two respects: participants in the Decision Group were tested on Pre-test and Post-test (objective measures) and received additional instructions, in the form of video feedback and modeling, which were not afforded the Behavior Group.

Insert Figure 1 about here

2.3.1. Pre-test, Mid-test, Post-test and Delayed Post-test

Subjective measures. Players were asked first to fill out a questionnaire regarding training age, hours of weekly training, and other relevant personal information. Player evaluation took place before the treatment (Pre-test), midway through the treatment condition (Mid-test) and at the end of the treatment condition (Post-test). During these evaluations, pairs were pseudo-randomly matched so that players from the Behavior Group competed against players from the Decision Group. The long-term changes (Delayed Post-test) were evaluated by assessing competitive play 4-6 months after cessation of the training intervention. For each player, five competitions against different opponents (minimum 42 to maximum 186 balls for each technique) were analyzed by two experts who rated the quality of movement production and the efficiency of transitions between forehand and backhand swings using the same criteria described for the other test sessions.

Objective measures. In addition to the subjective measures, the Decision Group's performance was also analyzed on two occasions (following Pre-test and Post-test), using a laboratory diagnostic conducted individually over a duration of approximately 90 minutes. Participants were allowed to warm up by playing some balls with the training coach. After warming up they were prepared with reflective markers and a systems check was run. The diagnostic was started if all equipment was working and markers could be read by the motion-analysis system.

Players had to hit a total of 400 balls onto a target placed on the other side of the table. Balls were served by a trained coach utilized for his ability to accurately serve balls to precise locations. Each trial consisted of one of four predetermined sequences of five strikes (sequences were developed during pilot testing). Each sequence contained three forehand and two backhand shots (Table 1). All four sequences were repeated five times (in random order) to produce 100 ball strikes per block. The training coach played each ball in the sequence by using a new ball from a basket, independent of how precisely the player responded. The training coach was provided with a written record of the 5-ball-sequence required on each trial. In the event of a mistake by the training coach (an average of two occurrences per player), the 5-ball-sequence was repeated. The first and third blocks were played at normal speed (comfortable for each individual player), the second and final blocks of 100 balls were delivered at competition speed (twice as fast as normal speed). To ensure speed synchronization, the training coach kept pace with a metronome. During the first two blocks, players were informed of the structure of the next trial sequence (i.e. 'we will now play three forehand shots followed by two backhand shots'). During the penultimate and final blocks, players were unaware of the impending sequence of shots. In sum, a block (100 balls) with low uncertainty and low speed, a block (100 balls) with low uncertainty and high speed, a block with high uncertainty and normal speed (100 balls), and a block (100 balls) with high uncertainty and high speed were presented. Between each set of 25 balls, a three minute break was allowed to avoid fatigue and collect balls. At the end of all blocks a video was taken of five minutes free play between the player and the training coach.

Insert Table 1 about here

2.3.2. Training Intervention

Players completed training diaries after each training session to control for individual differences in total training time and as a manipulation check of the consistency with which the coaches adhered to the training guidelines developed by the national coaches during the average 11 to 18 hours of weekly training.

Behavior Group: How decisions. The training intervention was conducted over a total of nine weeks. Training within the nine weeks was on how decisions. The Behavior Group received verbal feedback at regular intervals during all training sessions about forehand, and backhand strokes. The procedure of each single training session followed a structure of warm-up, main part of 'how' decision training and game play at the end. 'How' decisions for forehand involved repeating the forehand and backhand strokes to improve target accuracy, the starting point of the movement and the elbow position during the trajectory. The prescriptions for the forehand movement were: (i) a swing that starts at the horizontal level of the table should result in better performance than swings with starting points under the horizontal level of the table; and, (ii) the elbow should be close to the shoulder vertical line.

Decision Group: 'How' and 'what' decisions. The same amount of training as for the Behavior Group was conducted for the Decision Group over a total of nine weeks. Training within the nine weeks was divided in two parts. Part one contained technical training of forehand and backhand technique ('How' training), identical to the Behavior Group; part two consisted of transition training between forehand and backhand ('What' training). The prescription for 'what' decisions' from one movement to another was defined to be optimal if the movement trajectory from the end of the forehand (or backhand) near the head proceeded directly to the next stroke (either forehand or backhand) rather than to the neutral (ready) position prior to commencing the next stroke. This reduces the total trajectory length between two strokes, enabling faster returns. National coaches prepared an individual training program based on the feedback from player evaluations. The Decision Group received video feedback of their performances during open play recorded during the laboratory diagnostic session.

Video content for the Decision Group's feedback was designed in consultation with the National coaches. An appropriate selection of each player's movements were shown in a video that also showed senior National players (Germany's best players at the time) conducting forehand, backhand, and transition movements appropriately. Two videos were prepared for each player; one that concentrated instruction on how to perform forehand and backhand techniques correctly (the 'How' video) and a second containing sequences of transitions between forehand and backhand (the 'What' video). The 'How' video was used during the first half of the training intervention (weeks 2-6), the 'What' video was used during the second half. The video was shown at the beginning of each training session prior to warm-up; thus, participants were provided video feedback five times in a regular week of daily training. The 'how' and 'what' videos were each 10 minutes long and ordered for all players in the same way. First, the Sydney Olympic Games hymn was played, followed by one of the famous long 'rallies' from the Sydney Olympic games final, then the name of the player receiving the feedback, and a text explaining the following content. Second, top senior National players were shown performing the techniques under inspection. Next, selected player movements were shown accompanied by a narrative focusing attention on technique or transitions. The sequence of own and senior players' performances was repeated for each technique under evaluation. The video ended with a short clip of the participant's own open play against the training coach. This paradigm has been evaluated previously; Bert and Raab (2003) provide evidence for increased table tennis performance as well as attention focusing properties. The videos used here contained a specific instruction to focus either on technique or transitions. The attention focusing instruction was necessary to allocate attention to either 'how' (first part of the training) or 'what' (second part of the training) because in both videos players were able to observe their performance in both 'how' and 'what' decisions. The attention focusing technique has also been shown to impart superior performance effects compared to passive observation (Daugs, et al., 1990).

2.4. Materials and Measurement

Subjective measures. Two National level table tennis coaches evaluated players' techniques during a training competition prior to, midway through, and twice after intervention. Motivation was self-reported after each test by one question on a Likert-Scale ranging from 1 to 6 (1 = not motivated and 6 = very motivated).

Ratings of forehand and backhand swings were recorded using a Likert scale ranging from 1 to 6 (1 = very poor and 6 = excellent). The long-term effects of the treatments were also analyzed in a Delayed Post-test. For each player, videos of six competition matches played one and three months after the experimental intervention, were analyzed by both national coaches (inter class correlation for inter-rater reliability of $r = .91$, $p < .05$). Their analysis included all techniques (e.g. service, first counter, footwork and different styles of forehand and backhand strokes); however, only the forehand and backhand (‘how’ decisions) are reported in the results, in order to maintain consistency with the previous analyses. Transitions between movements were evaluated in the same manner as the ’How’ decisions by using a Likert scale ranging from 1 to 6 (1 = very poor and 6 = excellent).

Objective Measures. During the laboratory sessions, players returned shots to a square target on the left upper and outside corner of a standard table tennis table. Accuracy was calculated as the sum of points hitting different parts of the target. Four points were awarded for hitting the 20 x 20 cm central square, three points for hitting the 40 x 40 cm square, two points for hitting the 60 x 60 cm outer square, one point for clearing the net and landing on the other side of the table outside the target zone, and zero points for any other ball (missing, net, out). Balls were served by a trained professional to provide maximum consistency coupled with ecological validity.

Players were equipped with a prepared table tennis bat and were required to wear a black arm cover with markers attached to the arm at the shoulder joint, elbow and wrist. Markers were also fixed to the top of the bat and in the middle of the table end (player’s end). Three synchronized video cameras (space was calibrated before testing with an axial system of

2 x 2 x 2 meters) were distributed around the player to record performance accuracy and joint kinematics. The three dimensional data (50Hz sampling rate) of every marker (bat-top, wrist, elbow, shoulder, table) was manually digitized (Simi-Motion Software, Butterworth filter of 2nd order) for three sequences within the middle portion of each block.

Movement parameters selected for analysis were based on target descriptions of the movement recommended by the German Table Tennis Association (DTTB, 2001) and the National coaches (see Training Intervention). Two prescriptions for how to execute a movement were provided by the coaches and subsequently tested in the analysis of the movement data. The efficacy of each prescription was tested relative to performance outcome.

The overall coordination pattern of transitions between forehand and backhand strokes was analyzed by assessing differences in biomechanical degrees of freedom. The number of degrees of freedom exploited for movement production was calculated independent of real space. This was done to reduce error noise when comparing inter-individual or intra-individual data over time. One solution to measure the variability of the movement independent of the actual movement space is to use principal component analysis (PCA, see Haas, 1995). The structure of individual components can also be utilized to describe how movements are coordinated. For example, components may be constructed from neighboring joints within one or more dimensions of the Euclidean movement space. For some skills, it would seem almost essential that joint movements be highly correlated, therefore loading on the same component, in order to produce successful outcomes. Other skills may require a decoupling of certain joint movement planes. This does not exclude the possibility of changing strategies during learning or for the existence of different subcategories of a particular class of skills. A qualitative and quantitative view of the dimensions between joints represents a description of changes in type and amount of components over learning (for a similar description, see Huys, Daffertshofer, &

Beek, 2004). This procedure calculates the number of independent components (unrotated factor solution); the higher the number of components the greater the variability and the higher the number of degrees of freedom that a movement possesses. For this calculation the x-, y-, z-axis data from all marker traces (except the table marker, which has zero variance) during each block of trials of each individual were normalized and used as variables. Trials were excluded from analysis if less than 90% of the data points were detected by the motion system. When missed data points were less than 10% of the total trace, data was inserted using a linear regression between the five points preceding and five points following a missing section (the regression was conducted in forward and backward directions). Component analysis was run for each participant (in the Decision Group) over all trials for both Pre-test and Post-test.

3. Results

A significance criterion of $p < .05$ was established for all results reported. Eta-square were given for all analyses except for comparison of "time of testing" in which corrected eta-squares are presented. Prior to testing the main hypothesis, moderating effects of training hours and quality of training were assessed using player's training diaries. There were no statistically significant moderating influences from these factors and the check of motivation.

3.1. Subjective performance measures

A Group by Test (2 x 4) Analysis of Variance (ANOVA), with repeated measures on the latter factor (Pre-test, Mid-test, Post-test, and Delayed Post-test), was conducted taking expert ratings of technical performance ('how' decisions) and transition efficiency ('what' decisions) as dependent variables. A significant main effect for Test 'what' decisions $F(3, 18) = 43.71$, $p <. 01$, $\eta^2 = .73$; 'how' decisions $F(3, 18) = 28.28$, $p <. 01$, $\eta^2 = .58$, demonstrated improvements for both groups over time. Significant effects of Group were found for both ‘how’, $F(1, 18) = 58.37, p < .01, \eta^2 = .91$, and ‘what’ decisions, $F(1, 18) = 31.49, p < .01, \eta^2 = .75$, reflecting higher ratings for the Decision Group (Figure 2).

Insert Figure 2 about here

A univariate analysis of technical (‘how’) performance during the first six weeks (Pre- to Mid-test), revealed a group difference for forehand, $F(1, 18) = 56.07, p < .01, \eta^2 = .89$, and backhand, $F(1, 18) = 31.05, p < .01, \eta^2 = .72$.

Improvements Mid-test to Post-test were present in a univariate analysis showing that the Decision Group maintained its advantage over the Behavior Group for ‘what’ decisions. The advantage of the Decision Group for ‘how’ decisions was maintained from Mid-test to Post-test. This effect was stable for forehand, $F(1, 18) = 16.10, p < .05, \eta^2 = .68$, and backhand, $F(1, 18) = 24.42, p < .01, \eta^2 = .70$, and, more importantly, for the transitions between forehand and backhand, $F(1, 18) = 34.69, p < .01, \eta^2 = .75$.

The group differences for Delayed Post-test indicated higher transition scores (‘what’ decisions) for the Decision Group, $F(1, 18) = 12.71, p < .05, \eta^2 = .59$, no significant differences for forehand swings and superior movement execution by the Behavior Group for backhand swings, $F(1, 18) = 18.11, p < .05, \eta^2 = .68$. There was no significant Group x Test interaction. Thus, with the exception of ’how’ decisions in the Delayed Post-test analysis, the Decision Group performed better than the Behavior Group on subjective performance measures of both ‘how’ and ‘what’ decisions.

3.2. Objective performance measures

3.2.1. Accuracy

A 2 x 4 x 2 x 2 ANOVA (time of testing x type of sequence x sequence information x speed), taking shot accuracy as the dependent variable, revealed performance advantages (greater accuracy) from Pre-test to Post-test, $F(1, 27) = 13.62$, $p < .01$, $\eta^2 = .65$, during sequences with fewer transitions, $F(3, 27) = 3.83$, $p < .05$, $\eta^2 = .30$, known sequence structure, $F(1, 9) = 47.22$, $p < .01$, $\eta^2 = .84$, and when played at normal speed, $F(1, 9) = 104.71$, $p < .01$, $\eta^2 = .92$. In addition, the interaction between speed and type of sequence was significant, $F(3, 27) = 7.95$, $p < .01$, $\eta^2 = .47$, reflecting better performance during sequences with lower numbers of transitions played at low speed.

To test whether making the decision to change between forehand and backhand strikes affected shot accuracy (balls on target, see Method), all hits after a transition were compared with hits without a transition. This was calculated for positions two, three and five within the sequences because transitions always occurred at position four (see Table 1). No effect of transition was found; shots played following a transition were no poorer than shots that did not follow a transition. However, an effect of position (early or late in the sequence of five shots) was found for shots without prior transitions, $p < .05$. Accuracy was greater for position 5 compared to earlier positions (position 2, $M = 2.62$, $SD = .68$; position 3, $M = 2.95$, $SD = .56$; position 5, $M = 3.38$, $SD = .96$).

3.2.2. Movement analysis.

The previous analysis revealed expected differences in target accuracy in different conditions that should also be reflected by changes in kinematics. The analysis of kinematics for the Decision Group was necessary to separate learning of 'how' decisions such as backswing movements and elbow position for forehand and backhand and 'what' decisions such as the transitions between backhand and forehand and the structure of these movements in component analyses.

'How' decisions: Backswing movements. The movement trajectory of the backswing was predicted to be reduced if 'how' decisions follow the norms of the National coaches. The

starting position of the backswing movement relative to table height was reduced significantly from Pre-test to Post-test, $F(1, 985) = 118.73$, $p < .01$, $\eta^2 = .89$; the mean reduction was about 20 cm. The starting point of the backswing correlated positively but not significantly with error scores during the Post-test, $r = .65$, $p = .078$. In comparison, the relation between the starting point of the backswing and accuracy was less pronounced in the Pre-test, $r = .13$, $p > .1$.

'How' decisions: Elbow position. The distance between elbow and body needs to be reduced for stable forehand and backhand movement trajectories, as indicated by the National coaches. The average distance between elbow and body (vertical line from shoulder) was about 20 cm. Changes from Pre-test to Post-test were significant for five sequence-speed combinations (Bonferroni corrected, $p < .01$).

'What' decisions: Movement transitions. The transitions between forehand and backhand movements should reflect a small trajectory from a forehand to a backhand swing and vice versa. Following the completion of a shot, players either returned to a neutral position or remained in the terminal position to await the next shot. Returning to a neutral (ready) position is associated with longer movements. The mean transition movement was about 30 cm in the Pre-test, whereas this was reduced to 18.5 cm in the Post-test. Transition was longer in normal speed compared to high speed conditions (known sequence structure: normal speed: 12.5 cm, high speed 15.2 cm; unknown sequence structure: normal speed 15.3 cm, high speed 25.7 cm). The correlation between the length of the transition (average value over trials and sequences in y-axis of the hand wrist) and the accuracy score in the Post-test was moderate and negative, $r = -.46$, $p > .05$, indicating that longer transitions are not significantly associated with poorer accuracy.

'What' decisions: Component analyses. If transitions between movements became less variable over training, then the number of components should have been reduced from Pre- to

Post-test. Component analysis revealed fewer components in the Post-test (*M* = 5.25, *SD* = .66) compared to the Pre-test (*M* = 7.5, *SD* = .95), indicating more stable movement production. Furthermore, a differentiation of certain and uncertain sequences was found. More components were present in unknown sequences (*M* = 7.25, *SD* = .88) compared to known sequences (*M* = 5.5, *SD* = .88), indicating that players may have used sequence knowledge to prepare more concise movements. Further analysis of normal and high speed conditions demonstrated that movements could be represented with about two components less in normal speed compared to high speed, indicating lower variability in movement execution at normal speed. The reduction of components from Pre-test to Post-test in high speed conditions was more pronounced than in normal speed.

The correlation between the number of components and shot accuracy was, $r = -.59$, $p < .01$, for unknown sequences, indicating that fewer components are associated with greater accuracy. The correlation between the number of components and accuracy for known sequences was non significant and negative, $r = -.34$, $p > .05$, indicating a weaker relationship.

We found in the qualitative analysis of the components that in the z-dimension the freezing of up and down movements of the arm is present in nine different components for unknown sequences in the Pre-test, whereas in the Post-test the z-dimension is only present in three components. Movement trajectories in the z-dimension may be freed to compensate for the unknown variability in the sequences.

4. Discussion

The learning of ‘what’ and ‘how’ decisions was examined in a group of elite table tennis players. The results confirmed the hypothesis that a combination of behavioral and decision training significantly improves the performance of elite players compared to behavioral training alone. Data from coaches’ subjective ratings revealed performance improvements during three months of training intervention and during long-term follow-up analyses of competitive games. In addition, improvements in performance accuracy and movement kinematics from Pre-test to Post-test were present for the Decision Group. Results from subjective ratings support the idea that traditional behavioral feedback need not be abandoned in favor of decision training, as advocated by Vickers and colleagues (1999), but can be augmented with decision training to bring about technical and tactical improvements.

The subjective measures used to compare training methods provide little insight into the processes that are modified because of instructional interventions. For this reason, the Decision Group underwent two laboratory diagnostics designed to test specific aspects of their technique. Changes in performance were observed contingent on situational parameters (e.g., ball speed, sequence complexity, and sequence knowledge). A performance advantage was found for known sequences, sequences with fewer transitions, and sequences played at normal speed. The deleterious effects of higher speed and uncertainty on performance were not surprising; however, they extend research in table tennis that has shown similar results for single shots rather than over the complex sequence of shots used in the present study. The interaction between speed and uncertainty, high speed magnifies the performance decrement brought about by uncertainty, may provide valuable information for coaches.

Training schedules were based on prescriptions from National coaches who identified certain technical aspects of performance that were deemed crucial to expert performance. For example, backswing movements should start at the level of the table, not below; and the elbow should be close to the body. Both the backswing and elbow positioning improved during the training intervention, with starting point of the backswing correlated with performance; starting nearer to the table was associated with better performance. It is somewhat surprising that these aspects of performance are not already well learned in elite players. However, coaches often serve as opponents during training sessions and may not have sufficient time to monitor the early aspects of movement production. Delayed video feedback provides a mechanism for analyzing such aspects of play without time restraints. Furthermore, the work of Liao and Masters (2001) on implicit motor learning in table tennis, using analogy learning, may provide a useful method by which to present such important information to the performer.

We are aware of some critical issues within our design that needs to be controlled in further experiments. For instance, additional tests are needed to separate motivational, modeling and feedback effects of decision training. We want to stress that this study does however enhance our understanding of how decision training can improve how decisions without requiring manipulation of all aspects of the decision training environment (Vickers, 2003).

4.1. Video-feedback

We can only speculate about the mechanisms underlying the early advantages of the Decision Group compared to the Behavior Group. The superior performance of the Decision Group for both "what' and 'how' decisions was present during the Mid-test, prior to the introduction of 'what' decision training. This finding can be interpretated in different ways. First, the attention manipulation to the 'how' components of the video may not have been strong enough to prevent the Decision Group from also acquiring relevant information about 'what' decisions. This can be related to findings in simple tasks such as serial reaction tasks. There is ample evidence that the sequence of actions can be learned by event observation. Howard, Mutter, and Howard (1992), for example, showed that the performance of participants who acquired a serial reaction time task by simply observing the event was equivalent to participants who had physically performed the task during learning. Furthermore, Vinter and Perruchet (2002) supported the view that 'what' and 'how' decisions can be learned implicitly (without explicit knowledge) in more complex circle drawing movements. Thus, the superior performance of the Decision Group on ‘what’ decisions at Mid-test may have been because they benefited from passively observing this aspect of performance whilst watching the videos. This conjecture is somewhat speculative, but provides a basis for future research.

A second explanation could be that the performance differences are not attributable to the behavioral and decision aspects of the training but reflect other sources such as motivational or attentional effects. Although these and other explanations cannot be ruled out, they do not negate the finding that video feedback led to early improvements in both ‘how’ and ‘what’ decision making (and ultimately improved performance accuracy). The efficacy of video feedback is now well established (Hodges, Chua, & Franks, 2003), but the mechanisms by which this occurs remain controversial. For instance, Caroll and Bandura (1990) focused more on the role of error correction, whereas Hodges, et al.’s (2003) work focused more on error detecting and the ‘alerting role’ of video training. In addition, implicit perceptual learning has been proposed as a potential mechanism and has been demonstrated for other kinds of ‘what’ decisions in sport skills such as ball games (Raab, 2003) or returning serve at tennis. For example, Farrow, and Abernethy (2002) showed that implicit video-based perceptual training results in better predictions of service direction than explicit learning (although alternative interpretations of Farrow Abernethy’s (2002) results have been proposed by Jackson, 2003).

The debate about potential mechanisms for the early advantage of the Decision Group is out of the realm of the present study and cannot be elucidated from the current findings. Video feedback is used in this study as a tool to implicitly introduce ‘how’ and ‘what’ decisions, thereby enabling early advantages for ‘how’ and ‘what’ decision learning. Further research is required that explicitly separate potential explanations of why this effect occurs. For instance, further research is needed that compares how and what decisions for the behavior and decision groups on both objective and subjective measures. This experiment can at least potentially rule out pure instructional or motivational effects, as they were not found in our post-hoc motivational or instructional manipulations checks.

4.2. Practical recommendations

The debate about different ways of executing an accurate transition between different strokes is long-lived, but highlights important practical consequences. In Germany, for instance, National coaches receive players from different areas who have different transition techniques. The coaches must decide whether to optimize or retrain a specific technique without knowing exactly what the optimal technique is, as argued by Barchukova, and Voronov (1998). The results of the current experiment suggest that players should not return to a neutral position after playing a shot. In addition, the results indicate that a constant starting point is not a necessary constraint for precise movements; however, the start point should be located at about the level of the table and that smaller transition movements correlate with increased accuracy. The present data of the component analysis demonstrate a reduction in the number of joints and dimensions loading on each component when sequence structure is known. This may represent a strategic *freezing* of degrees of freedom in order to pre-program the sequence of movements. However, if the next movement is not known in advance, a *freeing* of degrees of freedom may allow on line motor adaptation to the evolving situation.

4.3. Conclusion

This article focuses on elite performers and asks how to improve their short- and long-term performance. Training normally results in learning, therefore any appropriate treatment should result in enhancements; however, it is also known that for elite performers large amounts of training are needed to induce rather minor improvements. We argue here that with a training load of 100 hours spread over a three month duration, measurable differences can be detected between elite players that deviate only in video training and type of treatment (e.g., decision versus behavioral). Previously, benefits of decision training over behavioral training were found only after extended periods of practice (Vickers, 2003). Our findings suggest that benefits are apparent even during the early stages of the training season by presenting ‘how’ and ‘what’ decisions on videos. Vickers argues that decision training exerts its influence by capturing the gestalt properties of a skill and equips the learner with early experience of ultimate performance goals. Alternatively, the high degree of complexity associated with learning skills in such a holistic way may encourage the use of implicit rather than explicit cognitive processes. Methodologies employed to date prevent the endorsement of any one candidate process as the mechanism that underlies benefits of decision training, but provides a working basis for future research.

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Table 1

Five sequences used equally over the course of the test (F=Forehand, B=Backhand)

#	Sequence	# of transitions	Position of transitions	Full anticipation of next ball
1	FFFBB	1	After the third ball	After the third ball
2	FBBFF	2	After the first, and third ball	After the third ball
3	BFFBF	3	After the first, third, and fourth ball	After the fourth ball
4	FBFBF	4	After the first, second, third, and fourth ball	After the fourth ball

Figure Captions

Figure 1. Temporal structure of Pre-test, Mid-test, Post-test, Delayed Post-test and the intervention for Behavior Group and Decision Group for objective and subjective measures. T1=Time 1.

Figure 2. Expert ratings of performance of 'how' decisions (full lines) and 'what' decisions (dotted lines) for Behavior Group (black filled squares) and Decision Group (white unfilled circles) on a scale from 1 (poor) to 6 (excellent) for Pre-test, Mid-test, Post-test and Delayed Post-test. Subjective ratings of how decisions represent averaged data from forehand and backhand.